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6 LIMITED FLIGHT EVALUATION OF SIDE STICK CONTROLLER FORCE-DEFLECTION CHARACTERISTICS ON AIRCRAFT HANDLING QUALITIES,

10 STEPHEN B. SMITH
PROJECT MANAGER

9 INTERIM REPORT,

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A limited pilot evaluation was conducted of the effect of side stick controller longitudinal and lateral force and deflection characteristics on the ability to perform certain prescribed tasks. Air-to-air, air-to-ground, and instrument approach and landing tasks were used in the evaluation. Twenty-three flights were flown in the Calspan NT-33A, variable stability aircraft. ~~from 13 May to 3 June 1977, at the Air Force Flight Test Center,~~

Block 20 continued:

~~Edwards AFB, California.~~ Data presented consists of Cooper-Harper pilot ratings and comments on each side stick configuration. The air-to-air tracking task consisted of the AFFTC "Handling Qualities During Tracking Technique". For this task, the evaluation pilots perferred the combination of relatively large control stick motion with light control force gradients and, to a lesser degree, the combination of relatively small control stick motion with heavy control force gradients. A fixed stick was not evaluated. The aircraft's lateral-directional characteristics were objectionable during this tracking task (rudder pedal inputs were not used), and detracted from the pilot's ability to evaluate lateral control effectiveness and control harmony. Based upon a limited number of tests, it appeared that varying control force harmony did not improve pilot ratings. Data gathered during air-to-ground tracking or during landings were insufficient and did not lead to any conclusions. The approach tracking task, which was to track the Edwards AFB instrument landing system, did not enable the pilots to finely discriminate between control configurations, and no conclusions could be drawn.

PREFACE

This program was conducted by the USAF Test Pilot School as a student class project under the sponsorship of the Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson AFB, Ohio. AFFDL funding was provided through AFFTC Job Order Number 8219A0, Project Directive 75-34.

The results of the test program were originally documented in a USAF Test Pilot School Letter Report (reference 1)[1] prepared by the following students of class 76-B: William M. Cima, Lieutenant, USN; Thomas J. LeBeau, Captain, USAF; Jack T. Stebe, Captain, USAF; Armand Jacob, Captain, French Air Force; and Charles M. Miller, Captain, USAF. This letter report has been expanded and edited for publication as an AFFTC Technical Report and released for general distribution.

The following acknowledgement is extracted from the preface to the letter report:

> "The test team received considerable assistance from Calspan Corporation personnel during this project and especially appreciates the advice and support of G. Warren Hall, Engineering Pilot, who acted as program safety pilot. Additionally, the test team thanks Robert Harper, Engineering Pilot, and Ronald Huber, Flight Test Engineer, for their assistance in preparing and executing this test. Finally, special recognition is due the Calspan NT-33A maintenance crews for their outstanding support in generating 100 percent of the sorties programmed."

[1]Reference 1: Cima, William M., Lieutenant USN, *et al.*, *Limited Flight Evaluation of Sidestick Controller Force - Deflection Characteristics on Aircraft Handling Qualities*, Letter Report, USAF Test Pilot School, Air Force Flight Center, Edwards AFB, California, 1 July 1977.

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INTRODUCTION

This report presents the results of a limited pilot evaluation of the effect of side stick controller longitudinal and lateral force and deflection characteristics on the ability to perform certain prescribed tasks. Air-to-air, air-to-ground, and instrument approach and landing tasks were used in this evaluation. The tests were flown in the Calspan, variable stability NT-33A using a side stick controller.

Flight testing was conducted between 13 May and 3 June 1977 at the AFFTC as part of the USAF Test Pilot School curriculum. A total of 23 flights were flown in the evaluation aircraft for 35.7 hours.

The test aircraft, NT-33A, USAF S/N 51-4120, was provided by the Calspan Corporation, Buffalo, New York, under AFFDL contract number F33615-73-C-3051. This aircraft differed considerably from a standard T-33 in that the aircraft dynamics and flight control system characteristics could be varied to simulate those of different aircraft.[2] The front cockpit was equipped with a fly-by-wire, variable feel side stick controller which was used exclusively during this test. The stability and control characteristics of a high performance fighter aircraft were used and are listed in table 1.

Handling qualities during selected tasks were evaluated with different ratios of stick force to aircraft response (load factor and roll rate) and stick force per unit of stick deflection. The longitudinal and lateral axes were investigated simultaneously.

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[2] A brief description of the test aircraft is given in Appendix C. Detailed information may be found in reference 2: Hall, G.W., and Huber, R.W., System Description and Performance Data for the USAF/CAL Variable Stability T-33 Airplane, AFFDL-TR-70-71, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, August 1970.

Table 1

STABILITY AND CONTROL CHARACTERISTICS OF TEST AIRCRAFT

Parameter	Flight Phase Category A Dynamics	Flight Phase Category C Dynamics
n_z/α (g/rad)	33	7
ω_{sp} (rad/sec)	5.0	2.2
$1/\tau_{\theta_2}$	2.1	0.9
ζ_{sp}	0.6	0.5
ω_p (rad/sec)	.09	.15
ζ_p	.05	.05
τ_R (sec)	.2	0.5
τ_s (sec)	∞	∞
ω_d, ω_ϕ (rad/sec)	3.2	1.2
ζ_d, ζ_ϕ	0.4	0.25
$\left\|\phi/\beta\right\|_d$	0.5	3.

NOTE: These characteristics are based upon 300 KIAS at 12,000 feet for Category A Flight Phase (tracking) and upon 145 KIAS at 4,000 feet for Category C Flight Phase (approach and landing). Proverse Yaw: $N_{\delta_a}/L_{\delta_a} = 0.016$.

This test was similar to a previous test performed by Calspan Corporation for the Air Force Flight Dynamics Laboratory[3] and was intended to supplement that data base. During the Calspan test, the pilots evaluated handling qualities during air-to-air tracking by performing operationally-oriented tracking maneuvers.

For this test, at the AFFTC, a nonoperational tracking task, "Handling Qualities During Tracking" (HQDT), was utilized. This procedure, unlike Calspan's, incorporated structured tracking maneuvers and did not permit the use of rudder pedals by the evaluation pilot during tracking.

In addition, the aircraft stability and control characteristics simulated on the NT-33 were slightly different from those used for the Calspan tests. A small amount of proverse yaw was introduced to improve the lateral-directional characteristics during tight tracking, with no rudder pedal inputs.

[3]Reference 3: Flight Investigation of Fighter Sidestick Force Deflection Characteristics, AFFDL-TR-75-39, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, May 1975.

TEST AND EVALUATION

OBJECTIVES

The primary test objective was to obtain pilot evaluations of specific aircraft handling qualities with variations in the following parameters:

1. Side stick longitudinal force per unit normal acceleration (F_{es}/n_z) and force per degree side stick deflection (F_{es}/δ_{es}) for flight phase Category A and C tasks.[4]

2. Side stick lateral force per unit roll rate (F_{as}/p) and force per degree side stick deflection (F_{as}/δ_{as}) for flight phase Category A and C tasks.

The secondary test objectives were to obtain the following:

1. Pilot evaluation of aircraft handling qualities with variations in control harmony for configurations where pilot comments indicated unsuitable control harmony.

2. A supportive, quantitative evaluation of tracking performance for flight phase Category A tracking tasks.

In addition, although not an original objective, a brief evaluation of the effect of heavier breakout forces was conducted.

SIDE STICK CONFIGURATIONS

The parameters varied in the test were:

1. Stick force per unit of aircraft response.

2. Stick force per unit of stick deflection.

Both the longitudinal and the lateral axes were varied together in the same manner as in the Calspan test reported in reference 3, (for example, a "heavy" longitudinal stick

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[4] Category A which includes air-to-air combat and ground attack and Category C which includes approach and landing are as defined in reference 4: Military Specification Flying Qualities of Piloted Airplanes, MIL-F-8785B(ASG), 7 August 1969.

force was used in conjunction with a "heavy" lateral stick force in order to provide control harmony). On a few tests the longitudinal and lateral axes were varied independently to investigate differences in control harmony. The levels of 1 and 2 above, planned for investigation, are depicted in tables 2 and 3. The heavy, medium, light, and very light stick force-to-response gains are depicted in figures 1 and 2 as plots of stick force versus aircraft response. The configurations are also represented in matrix form in figures 3 and 4. Although each matrix depicts only the longitudinal axis configurations, the lateral axis set is also defined by reference to the tables. The nonlinear character of the force-response gains were designed by Calspan to depict modern, fighter aircraft control mechanizations. The heavy, medium, and light gains were chosen to duplicate those of the Calspan test; the very light gain was added. However, as discussed later, these gains did not accurately match Calspan's. The same ratios of stick displacement (in degrees of arc) to stick force were used as in the Calspan test with the exception of the longitudinal and corresponding lateral gradients of 0.2 and 0.3 deg/pound, respectively. Calspan had tested a fixed-stick configuration (gradient of 0.0 deg/pound) and, in discussions with the TPS, had recommended that a very small amount of stick deflection also be investigated. The 0.2 deg/pound gradient was included for this reason.

CONDUCT

Evaluation Technique:

The side stick force-deflection configurations chosen for each mission were selected from tables 2 (Category A) and 3 (Category C). These configurations were arranged so that no two similar configurations were evaluated consecutively. At no time during the test program were the evaluation pilots exposed to the previously collected data or aware of the configurations tested.

Predefined air-to-air and air-to-ground tracking tasks were used to evaluate the side stick configurations in flight phase Category A. The "Handling Qualities During Tracking" technique in use at the AFFTC was employed.[5] The test limitations prescribed in Appendix B were adhered to. Instrument approach and landing tasks were used to evaluate side stick controller configurations in flight phase Category C.

[5]Reference 5: Twisdale, T.R., and Franklin, D.L., Tracking Test Techniques for Handling Qualities Evaluation, AFFTC-TD-75-1, Air Force Flight Test Center, Edwards AFB, California, May 1975.

Table 2

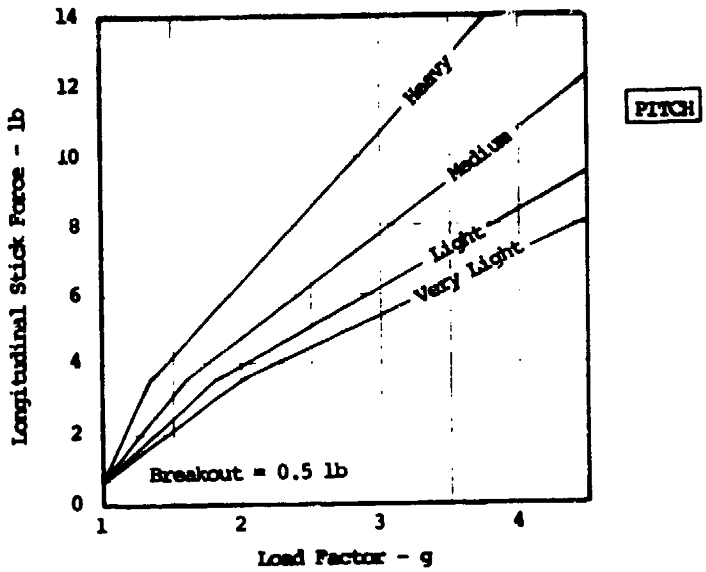
CATEGORY A CONTROL CONFIGURATIONS

Config. No.	F_{es}/n_z* (lb/g)	δ_{es}/F_{es} (deg/lb)	F_{as}/p* (lb/deg/sec)	δ_{as}/F_{as} (deg/lb)
1	very light	.2	very light	.3
2	light	.2	light	.3
3	medium	.2	medium	.3
4	heavy	.2	heavy	.3
5	very light	.5	very light	.77
6	light	.5	light	.77
7	medium	.5	medium	.77
8	heavy	.5	heavy	.77
9	very light	.7	very light	1.08
10	light	.7	light	1.08
11	medium	.7	medium	1.08
12	heavy	.7	heavy	1.08
13	very light	.91	very light	1.43
14	light	.91	light	1.43
15	medium	.91	medium	1.43
16	heavy	.91	heavy	1.43

*Terminology refers to the slopes of the force-response curves shown on the facing page.

FLIGHT PHASE CATEGORY A

300 kcas
12,000 ft



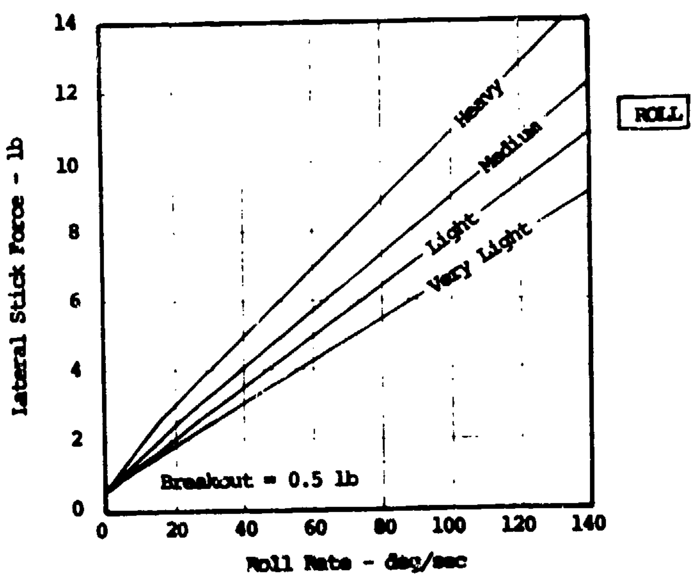


Figure 1 Control Force/Response Gains

Table 3

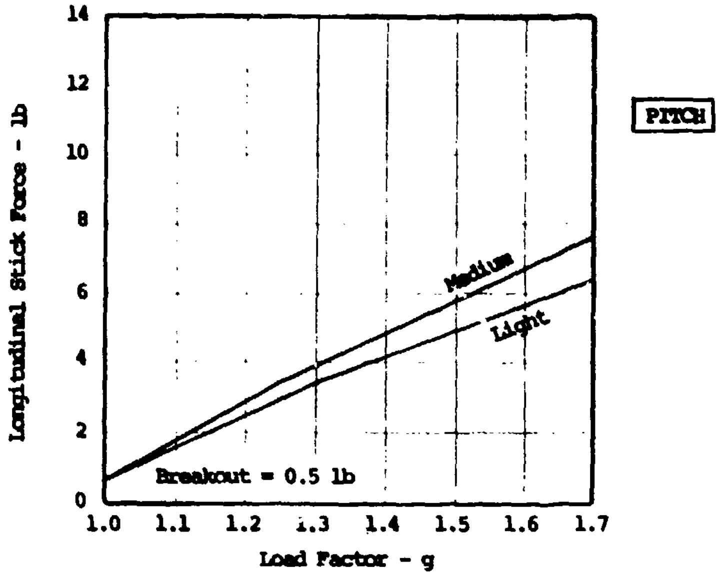
CATEGORY C CONTROL CONFIGURATIONS

Config. No.	F_{es}/n_z* (lb/g)	δ_{es}/F_{es} (deg/lb)	F_{as}/p* (lb/deg/sec)	δ_{as}/F_{as} (deg/lb)
17	light	0.2	light	0.3
18	medium	0.2	medium	0.3
19	light	0.5	light	0.77
20	medium	0.5	medium	0.77
21	light	0.7	light	1.08
22	medium	0.7	medium	1.08
23	light	0.91	light	1.43
24	medium	0.91	medium	1.43

*Terminology refers to the slopes of the force-response curves shown on the facing page.

FLIGHT PHASE CATEGORY C

145 knots
4,000 ft



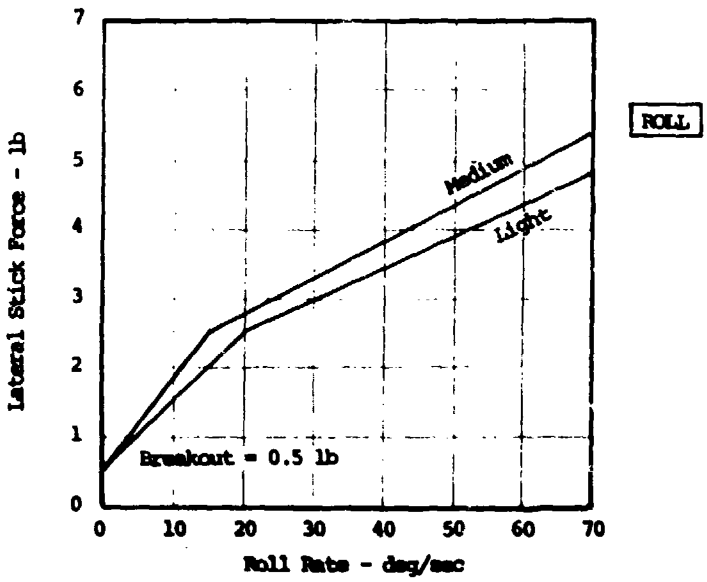


Figure 2 Control Force/Response Gains

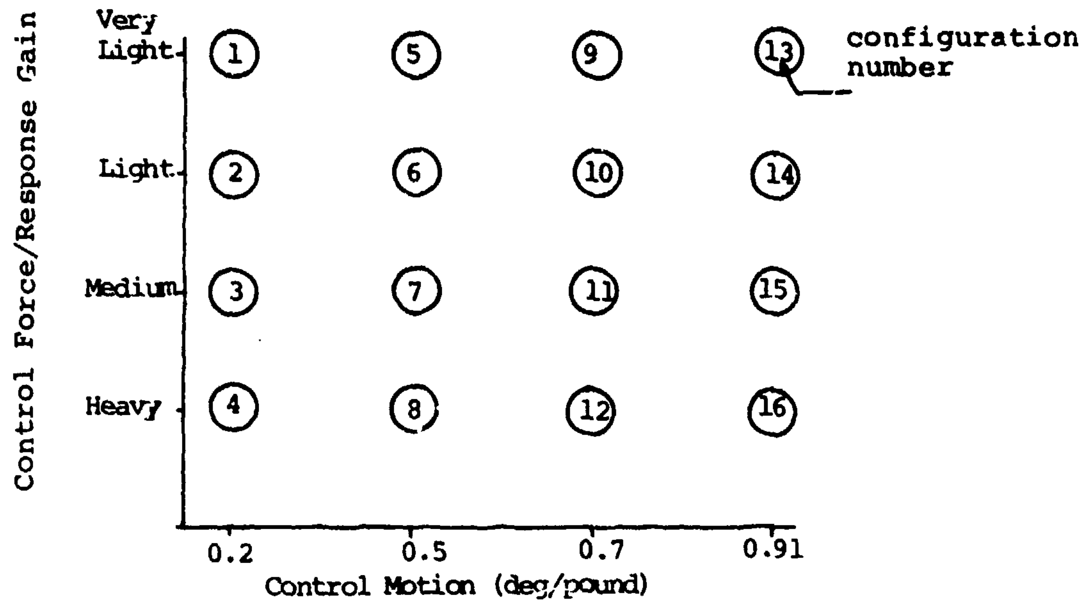


FIGURE 3 CONTROL CONFIGURATIONS FOR CATEGORY A TASKS

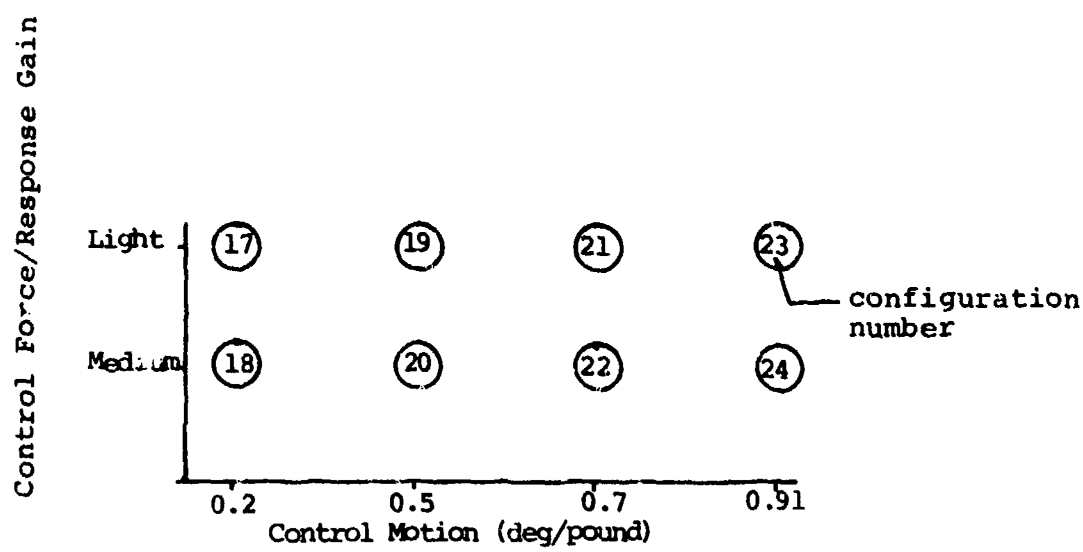


FIGURE 4 CONTROL CONFIGURATIONS FOR CATEGORY C TASKS

Air-to-air tracking was begun with the NT-33A approximately 2,000 feet behind the target aircraft. The pilot trimmed the aircraft prior to start and did not retrim during the maneuver. At the start of the test, the pilot achieved the aim point as rapidly and aggressively as possible and persistently drove the pipper to the precise aim point. The aim point was the center of the target fuselage at the wing/fuselage junction. The pipper depression was 15 mils. The specific tracking task for each configuration consisted of the following:

1. Two 280 KIAS 2-g turns in opposite directions for a heading change of approximately 180 degrees in each turn.

2. Two windup turns in opposite directions maintaining 280 KIAS from 1 to 3.5 g at an onset rate of 0.1 g/second.

The above sequence was accomplished for each side stick control configuration at least once, but repeated as often as desired by the evaluation pilot. The evaluation pilot then completed the in-flight debriefing shown in Appendix D and assigned a numerical rating using the Cooper-Harper rating scale (same Appendix). The control system was then reconfigured for the next point. All tests were conducted during day VFR conditions at altitudes from 17,000 feet mean sea level (MSL) to 13,000 feet MSL. The evaluation pilot maintained separation distance between 2,000 and 1,000 feet. The NT-33A oscillograph, audio recorder and gunsight camera were used for selected maneuvers.

For the air-to-ground tracking task, the evaluation pilot used a designated target within R2508, Edwards AFB restricted area. The air-to-ground simulated bombing pattern is depicted in figure 5 and tracking techniques described in reference 5 were used. The pipper depression was 15 mils. At the release altitude of 3,000 feet above ground level (AGL) a pullout employing 4 g's in 2 seconds and a climb to downwind were made. The above sequence was repeated as necessary for each of the control system configurations. Prior to the base turn, the evaluation pilot completed the in-flight debriefing in Appendix D. The oscillograph, the audio recording device and the gunsight camera were used on data passes.

For the approach task, the published ILS approach to Edwards AFB Runway 22 was flown with the evaluation pilot making an aggressive effort to stay oncourse and glide slope. At 200 feet AGL, the evaluation pilot transitioned to outside references for the landing task and completed a touch and go landing. When established on

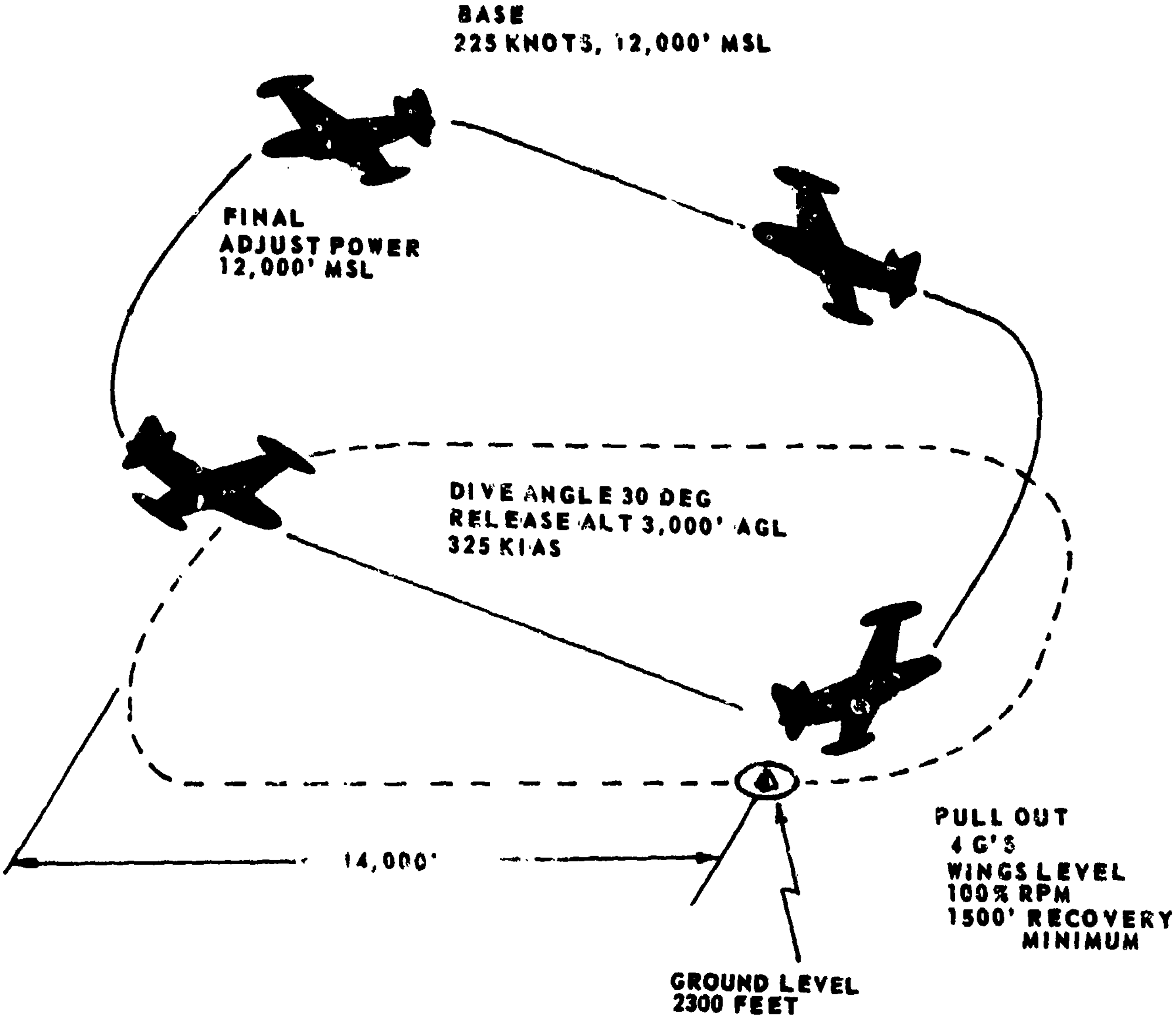


Figure 5 Dive Bomb Pattern

downwind, the evaluation pilot completed the in-flight debriefing in Appendix D. Oscillograph and audio recorders were used. The aircraft was flown at 140 KIAS with landing gear and speed brakes extended and flaps at 30 degrees.

When possible, a postflight debriefing was conducted with the project engineers and the safety observer in attendance. However, because of curriculum workload formal debriefings were not conducted on most missions, and the evaluation pilot transcribed his in-flight comments from the audio recorder.

Data Reduction:

Pilot comments were summarized on a flight-by-flight basis according to each task evaluated. These summaries were reviewed and condensed to those comments that typified each configuration and task combination.

Individual pilot Cooper-Harper ratings for each configuration and task combination were collated. Several different methods, listed below, were used to summarize pilot ratings.

1. Determining the average rating for each control configuration.

2. Determining the median rating for each control configuration.

3. Determining the average pilot rating for each of the three pilots over each control configuration. The average and median of these three averages were then computed.

4. Determining the median pilot rating for each of the three pilots over each control configuration. From these three median ratings, the average and median were then computed.

5. Calculating the standard deviations of all pilot ratings for each control configuration.

Oscillograph records were reviewed and data extracted when verification of test conditions was required, when anomalies occurred during testing that required further investigation, or when verification of aircraft stability and control characteristics and sidestick controller configurations were required.

Gun camera film was processed and read to provide pipper azimuth and elevation offset from the target for selected air-to-air tracking runs. Representative plots of pipper position versus target and error time histories were generated using the AFFTC Air-to-Air Gunnery Analysis System (ATAGAS) computer program.

RESULTS

Pilot rating and comment data were gathered and analyzed for the air-to-air, air-to-ground and approach and landing tasks. Control harmony and the effect of breakout force on pilot ratings were investigated during air-to-air tracking for selected configurations.

Air-to-Air:

The results of the air-to-air tracking tasks are presented in figure A1 (individual ratings) and in figures A2 and A3 (pilot averages and overall averages). Representative pilot comments for each side stick configuration are shown in figure A4. For purposes of discussion the matrix of control configurations was divided into four areas of similar pilot ratings and is depicted in figure A5.

The ratings were treated with a variety of statistical reduction techniques, as explained previously. However, each technique yielded essentially the same results. Therefore a simple average of all ratings for each configuration was used to present the results. Ratings were discarded only when the configuration was improperly set, and in one instance when the pilot reported that he was overly tired during the evaluation flight. Figure A6 shows the standard deviations for the ratings to be 1.5 or less for each configuration, indicating good correlation of ratings.

In general, pilots preferred the larger control stick motion with light control force gradients and, to a lesser degree, the smaller control stick motion with heavy control force gradients. Control configurations in area I of figure A5 yielded the best results, both in pilot ratings and comments. Pilots indicated that control motions were noticeably large but not uncomfortable. Area I configurations were on the edge of the test matrix; thus, the outer boundaries of this area were not determined. Additional testing should be accomplished to completely define area I. (R 1)[6]

Area II configurations were found to be acceptable but slightly inferior to area I configurations. Pilot comments indicated that the stick forces for configuration

[6] Numerals preceded by an R refer to recommendations appearing in the Conclusions and Recommendations section of this report.

4 were tiring and uncomfortable. Although the boundaries were not completely determined, these comments imply that area II would probably not extend into the range of heavier force gradients.

Area IV configurations were rated the poorest. They were characterized by longitudinal and lateral sensitivity or, in the case of configuration 16, aircraft sluggishness.

Area III includes all of the remaining control configurations. Note that with medium control stick motion, the control force gradient selected had essentially no effect on pilot ratings. However, pilot comments show a trend from oversensitivity to sluggishness as the control force gradient increased from very light to heavy.

The effect of breakout force on pilot ratings was investigated by setting control configurations 7 and 11 with breakout forces of 1/2 pound and 1 pound. Figure A7 shows that pilot ratings were worse for configuration 7 with 1 pound breakout as compared to ratings for 1/2 pound breakout force, and essentially the same for configuration 11. Pilot comments in figure A8 show an increase in pitch sensitivity with increased breakout force.

Control harmony was investigated for four selected control configurations where pilot comments indicated a lack of harmony. As shown in table 4, lateral forces were increased or decreased one gradient "increment" for a given longitudinal force gradient. Figures A9 and A10 show that the change in lateral forces resulted in essentially no change in pilot ratings. Pilot comments in figures A11 and A12 show that increasing the lateral force gradient generally resulted in increased sensitivity in the pitch axis while decreasing the lateral force gradient resulted in increased sensitivity in the roll axis. Thus, based upon this limited investigation, the original control force harmony appeared to be optimal. However, changes in control motion harmony were not investigated. Additional control harmony testing should be accomplished. (R 2)

Table 4

CONTROL HARMONY TESTS GAIN SETTINGS

Control Motion Gradient (deg/pound)	Longitudinal Force/ Response Gain	Lateral Force/ Response Gain
0.5, 0.7	light	very light
↓	medium	light
	light	medium

Early in the test program it became evident that an objectionable amount of adverse yaw was present during the tracking task. This adverse yaw so overshadowed other aircraft characteristics (since rudder pedal inputs were not allowed) that it was decided to alter the simulated dynamic characteristics from those used in the Calspan tests. The aileron-to-rudder interconnect gain was changed to produce a slight amount of proverse yaw. Tracking performance improved and allowed a better evaluation of both axes. However, the lateral-directional characteristics remained objectionable during the performance of the HQDT task. Sharp lateral inputs resulted in annoying, open loop, low frequency directional oscillations for all control configurations. This deficiency detracted from the pilot's ability to evaluate lateral control effectiveness and control harmony.

A minimum of one flight per pilot was necessary to adopt to the HQDT task and to the aircraft stability and control characteristics. Gunsight camera film was useful during this phase for aiding pilots in qualitatively evaluating configurations and exchanging ideas on adequate versus desired aircraft performance.

Gunsight camera film from six randomly selected flights was read and reduced to provide pipper position error using the AFFTC ATAGAS computer program. Plots resulting from three control configurations are presented in figures A13 through A15. The tracking error did not correlate completely with pilot ratings since the amount of pilot compensation could not be measured. Hence, these plots were not considered useful for this evaluation.

Air-to-Ground:

Evaluation of the air-to-air tracking task was considered primary and a target aircraft was available for each test sortie. This limited the number of air-to-ground and approach and landing tasks that could be accomplished. Only 12 pilot ratings, shown in figure A16, were obtained for the air-to-ground tracking task. This amount of data was insufficient to present conclusions on the control configurations.

Approach and Landing:

Approach and landing data are presented in figures A17 through A19. Pilot comments and ratings indicated that approach and landing should be evaluated as two separate tasks. Further, the approach tracking task did not enable the pilots to finely discriminate between control configurations. Nearly all control configurations seemed to accomplish the approach tracking task equally well. The landing task enabled pilots to discriminate more easily between control configurations, however, insufficient data were obtained to present conclusions. Additional testing should be accomplished to optimize the control configurations for the landing task. (R 3)

Comparison With Previous Data:

The air-to-air tracking data were compared to the data base previously established by Calspan and reported on in reference 3. Ideally, the test configurations flown and the tasks rated should have been the same in both programs. However, there were differences, listed below.

1. The aircraft dynamic characteristics were altered by introducing a slight amount of proverse yaw.

2. The tracking maneuver technique precluded the use of rudder pedals and, as such, accentuated any lateral deficiencies.

3. The force/response gains used in tracking were higher than the corresponding values chosen by Calspan. Generally, during tracking, pitch stick was confined to the upper gradient (above the gradient change) and roll stick to the lower gradient. In these areas the Calspan gradients fell approximately halfway between the gradients depicted in figure 1.

4. The breakout forces employed in these tests were 1/2 pound. Calspan used one-pound breakout forces.

5. During the AFFTC tests the pilots were not informed as to which configuration they were evaluating. During the Calspan tests, they were so informed.

Because of these differences, caution should be used when trying to relate the two groups of data.

The configurations most relatable to those tested previously were numbers 6, 7, 8 (0.50 deg/pound motion gradient) and 14 and 15 (0.91 deg/pound). In the case of the smaller motion the pilot comments are supportive but the AFFTC ratings tended to be worse. This is attributed to the more demanding tracking task. The Calspan results showed that pilot comments and ratings improved when a slight amount of stick motion was introduced but they degraded as stick motion was further increased. The AFFTC data showed the improvement to continue out to the largest motion tested (0.91 deg/pound) for the light and medium force-response gradients. The conclusion that the larger stick motion caused a tendency towards sluggishness and overcontrol and a degradation in predictability in response was not borne out by pilots in the AFFTC test with the exception of the heavy force-response gain.

Further Testing:

The pilot ratings and comments presented in this report are applicable to the specific tasks described in the Conduct section. Other tasks, such as gross maneuvering or formation flying, may result in different ratings and comments for the same control configurations. Further testing should be conducted to determine the applicability of these test data to other tasks. (R 4)

CONCLUSIONS AND RECOMMENDATIONS

For the air-to-air tracking (HQDT) task the evaluation pilots preferred the larger control stick motion with light control force gradients and, to a lesser degree, the smaller control stick motion with heavy control force gradients. The aircraft's simulated lateral-directional characteristics were objectionable during this tracking task and detracted from the pilot's ability to evaluate lateral control effectiveness and control harmony. Based upon a limited number of tests, it appeared that varying control force harmony did not improve pilot ratings. Data gathered during air-to-ground tracking or during landings were insufficient and did not lead to any conclusions. The approach tracking task did not enable the pilots to finely discriminate between control configurations.

Some of the configurations with the best ratings involved large stick motion and were on the edge of the test matrix; thus, the outer boundaries of this area were not determined.

1. Additional flight phase Category A tracking tests should be accomplished to completely define the area of best ratings (page 20).

The control harmony investigation was incomplete in that control motion harmony was not evaluated and that the entire matrix of control configurations was not investigated.

2. Additional control harmony testing should be accomplished (page 21).

Insufficient data were obtained for Category C landing tasks to present conclusions.

3. Additional testing should be accomplished to optimize the control configurations for the landing task (page 23).

Other tasks, such as gross maneuvering or formation flying may result in different ratings and comments for the same control configurations.

4. Additional testing should be conducted to determine the applicability of these test data to other tasks (page 25).

REFERENCES

1. Cima, William M., Lieutenant USN, et al., Limited Flight Evaluation of Sidestick Controller Force - Deflection Characteristics on Aircraft Handling Qualities, Letter Report, USAF Test Pilot School, Air Force Flight Test Center, Edwards AFB, California, 1 July 1977.

2. Hall, G. W., and Huber, R. W., System Description and Performance Data for the USAF/CAL Variable Stability T-33 Airplane, AFFDL-TR-70-71, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, August 1970.

3. Flight Investigation of Fighter Sidestick Force - Deflection Characteristics, AFFDL-TR-75-39, Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, May 1975.

4. Military Specification, Flying Qualities of Piloted Airplanes, MIL-F-8785B(ASG), 7 August 1969.

5. Twisdale, T. R., and Franklin, D. L., Tracking Test Techniques for Handling Qualities Evaluation, AFFTC-TD-75-1, Air Force Flight Test Center, Edwards AFB, California, May 1975.

6. Cooper, G. E., and Harper, R. P. Jr., The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities, NASA TN D-5153, Ames Research Center, Moffett Field, California, April 1969.

7. Twisdale, Thomas R., Preflight Briefing and Postflight Debriefing Outlines for Handling Qualities Testing and Evaluation, Flight Test Technology Branch Office Memo, Air Force Flight Test Center, Edwards AFB, California, February 1977.

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APPENDIX A

TEST DATA

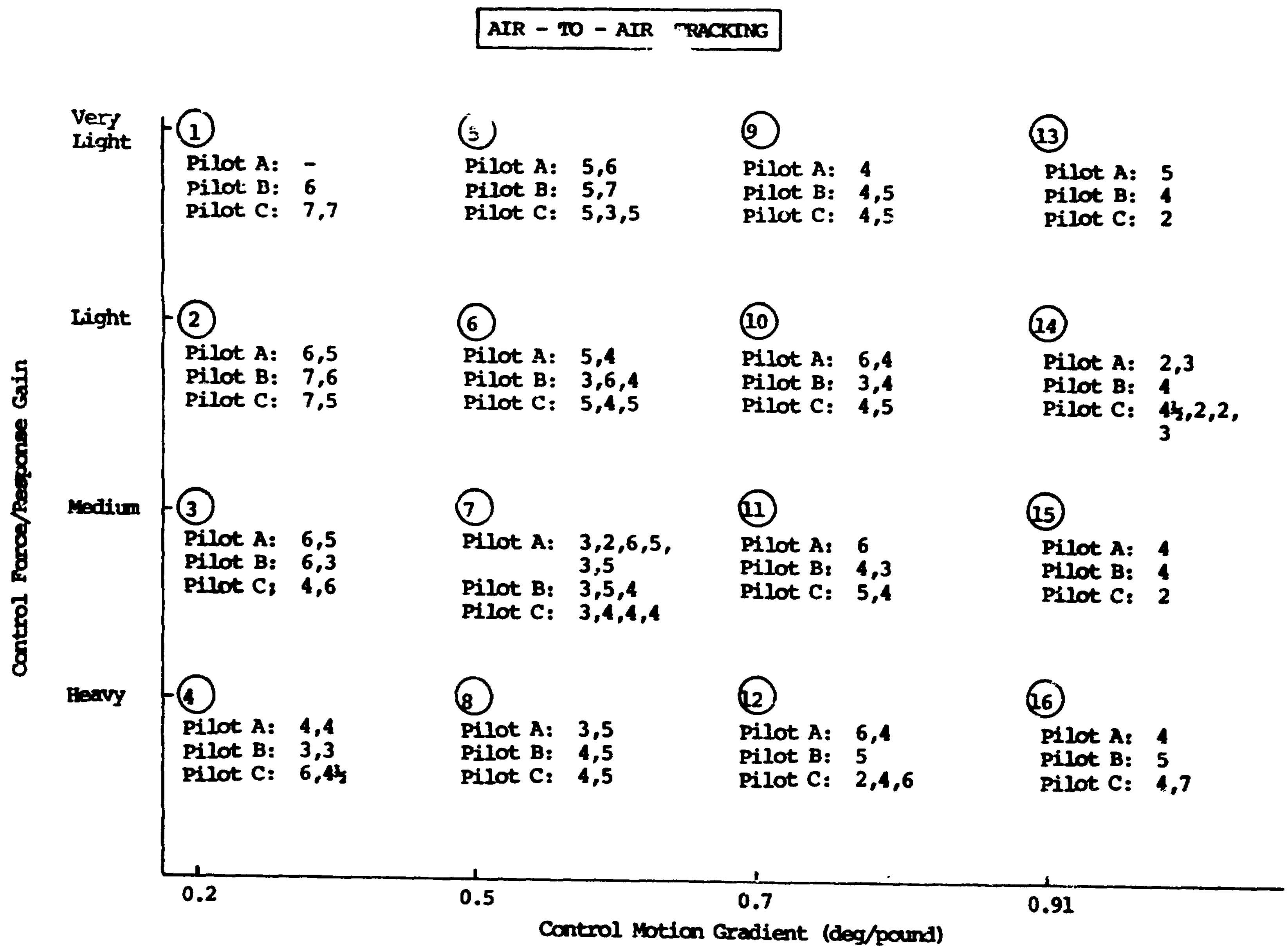


Figure A1 Individual Pilot Ratings

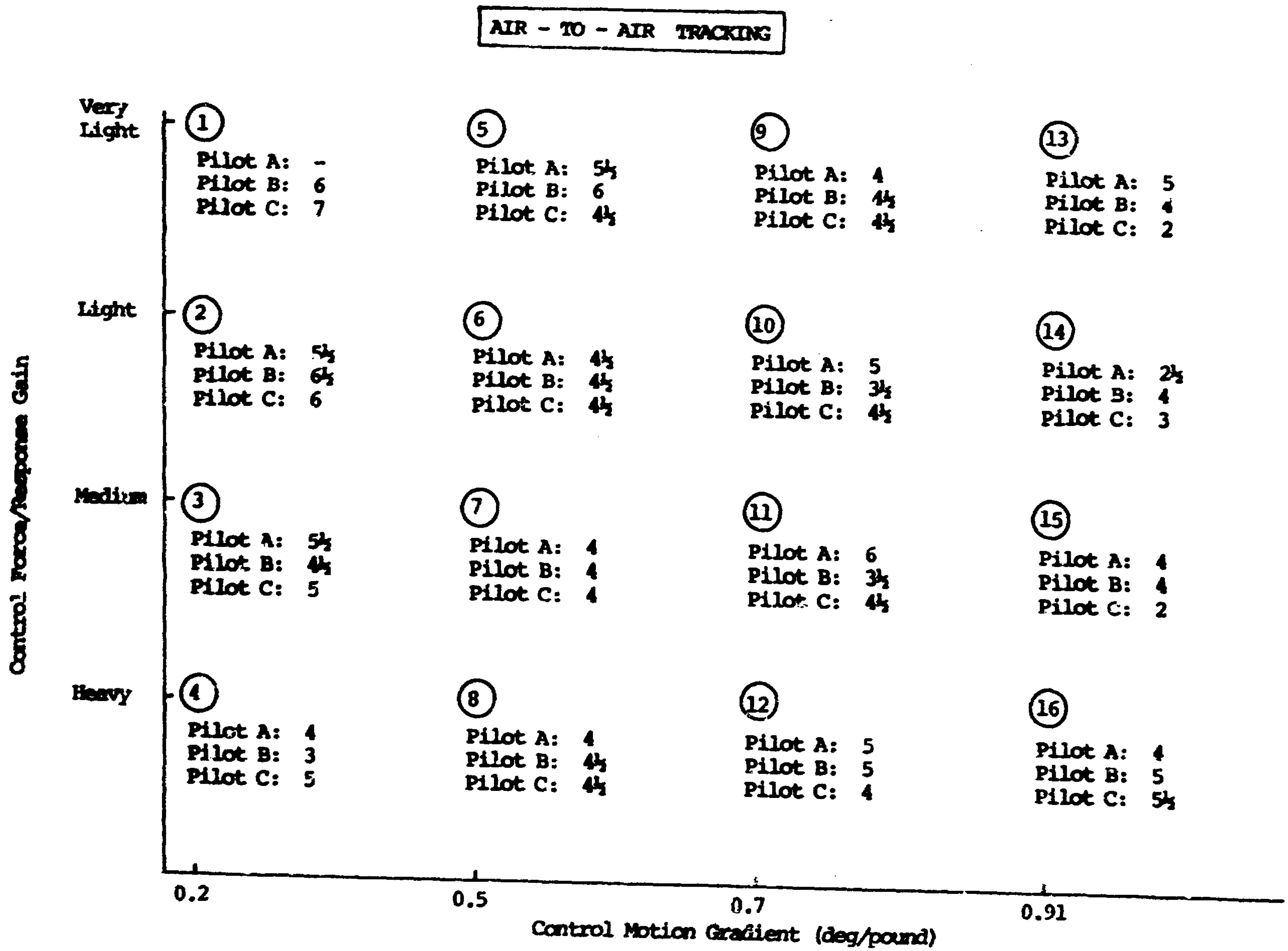


Figure A2 Individual Averages of Pilot Ratings

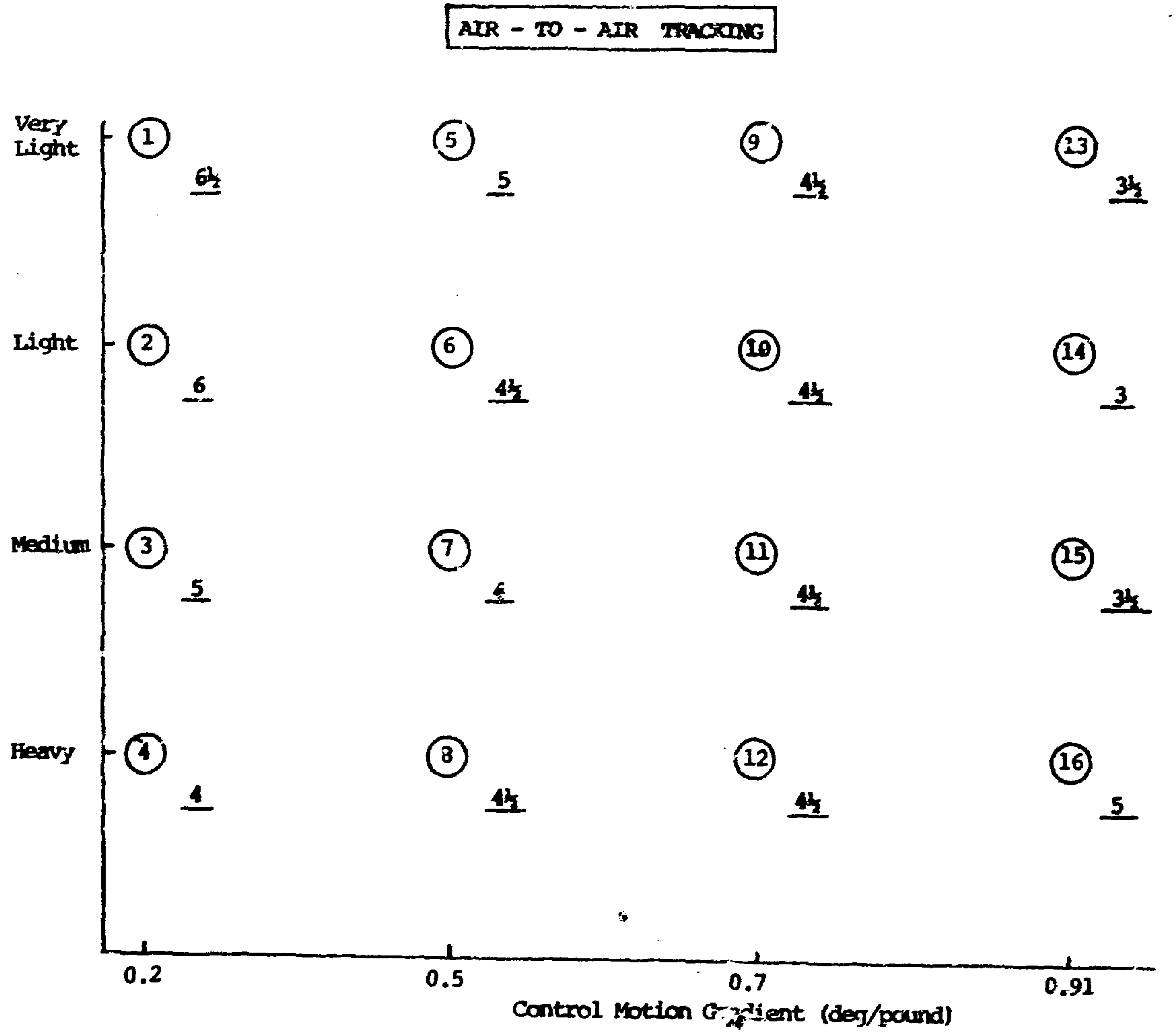
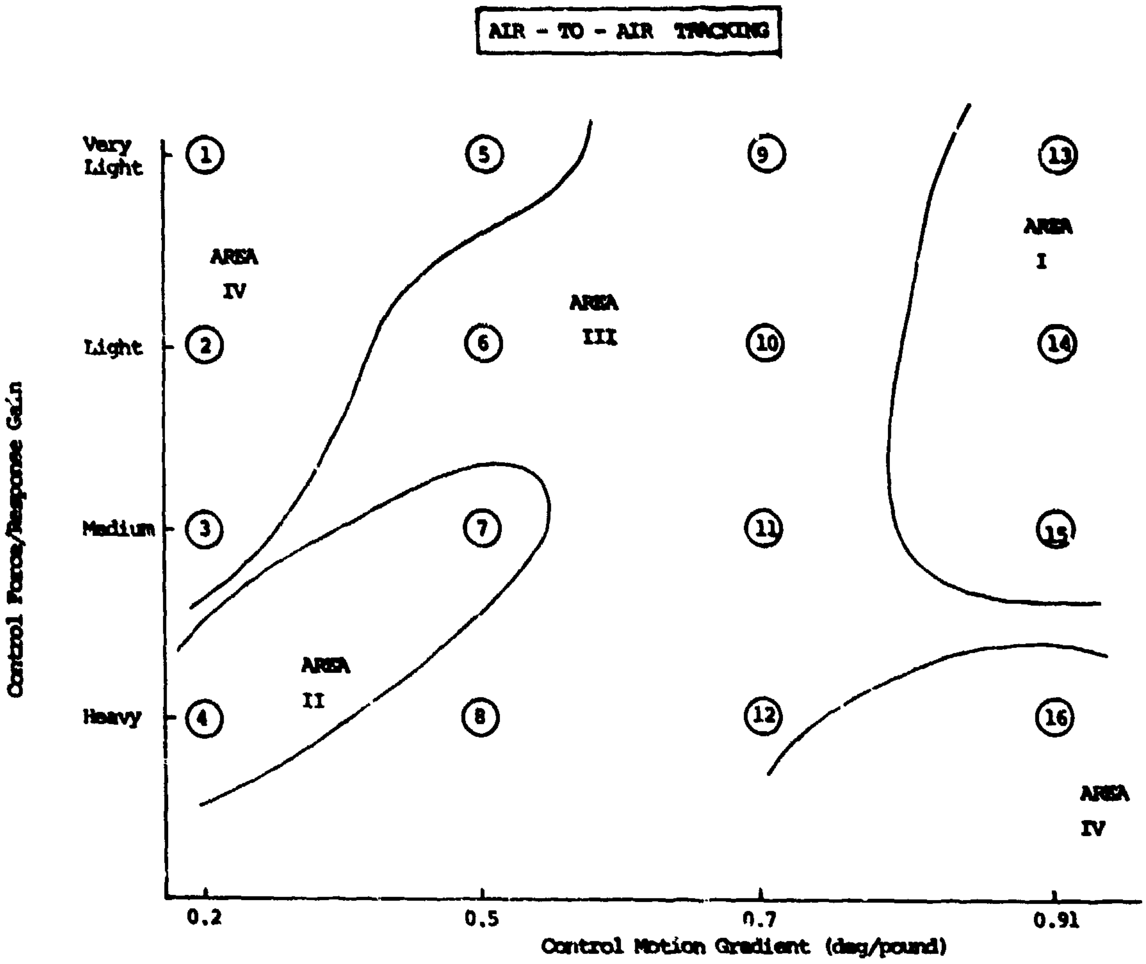


Figure A3 Average Pilot Ratings

AIR - TO - AIR TRACKING

Control Force/Response Gain \ Control Motion Gradient (deg/pound)	0.2	0.5	0.7	0.91
Very Light	(1) Pitch extremely sensitive. Lateral fair. Avg CH of 6½.	(5) Pitch and lateral both a little too sensitive. Avg CH of 5.	(9) Pitch and lateral are both too Sensitive. Avg CH of 4½.	(13) No pitch bobble tendency but imprecise positioning. Avg CH of 3½.
Light	(2) Pitch too sensitive. Lateral wandering and sensitive. Avg CH of 6.	(6) Slight pitch bobble. Better @ high g's. Lateral sluggish (possibly cont. harmony). Avg CH of of 4½.	(10) Pitch a little sensitive. Lateral bobble. Avg CH of 4½.	(14) Pitch and lateral steady and responsive. Motion noticeably large. Avg CH of 3.
Medium	(3) Pitch a little sensitive. Lateral slow to respond. Avg CH of 5.	(7) Pitch steady once on tgt. Lateral forces high (possibly cont harmony). Avg CH of 4.	(11) Very slight pitch bobble tendency but good. Large lateral corrections difficult. Lat forces high & bobble. Avg CH of 4½.	(15) Motion noticeably large. No pitch bobble, slightly sluggish. Avg CH of 3½.
Heavy	(4) Pitch very stable at higher g's, but forces tiring. Avg CH of 4.	(8) Pitch steady but forces too heavy. Lateral forces too heavy. Tiring. Avg CH of 4½.	(12) A/C sluggish but stable. Forces heavy. Avg CH of 4½.	(16) A/C very sluggish and forces uncomfortable. Avg CH of 5.

Figure A4 Summary Of Pilot Comments



NOTE:	RANGE OF AVERAGE RATINGS -		
	AREA	I	3 - 4
		II	4
		III	4 - 5
		IV	5 - 6½

Figure A5 Areas of Similar Pilot Ratings

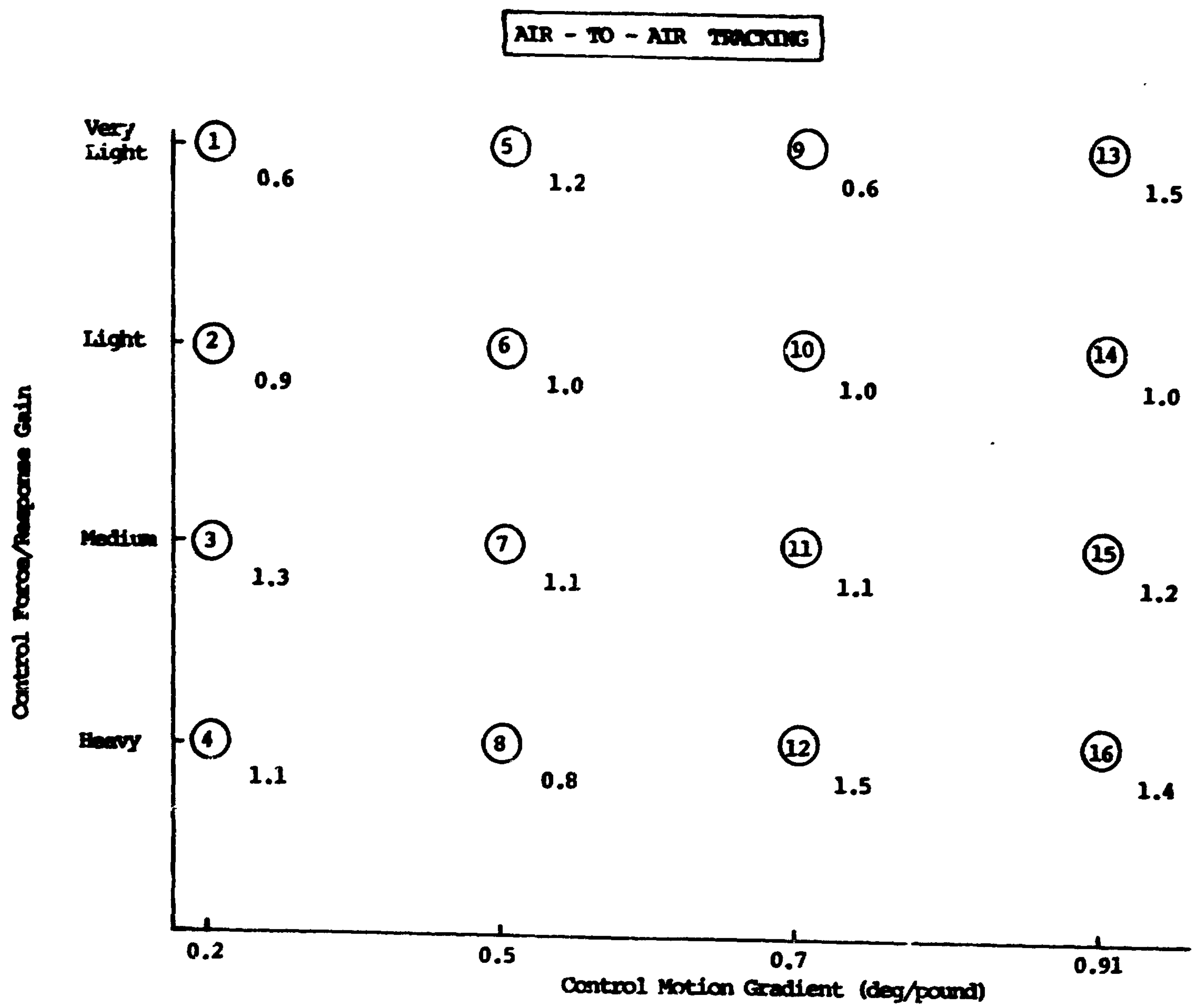


Figure A6 Pilot Rating Standard Deviations

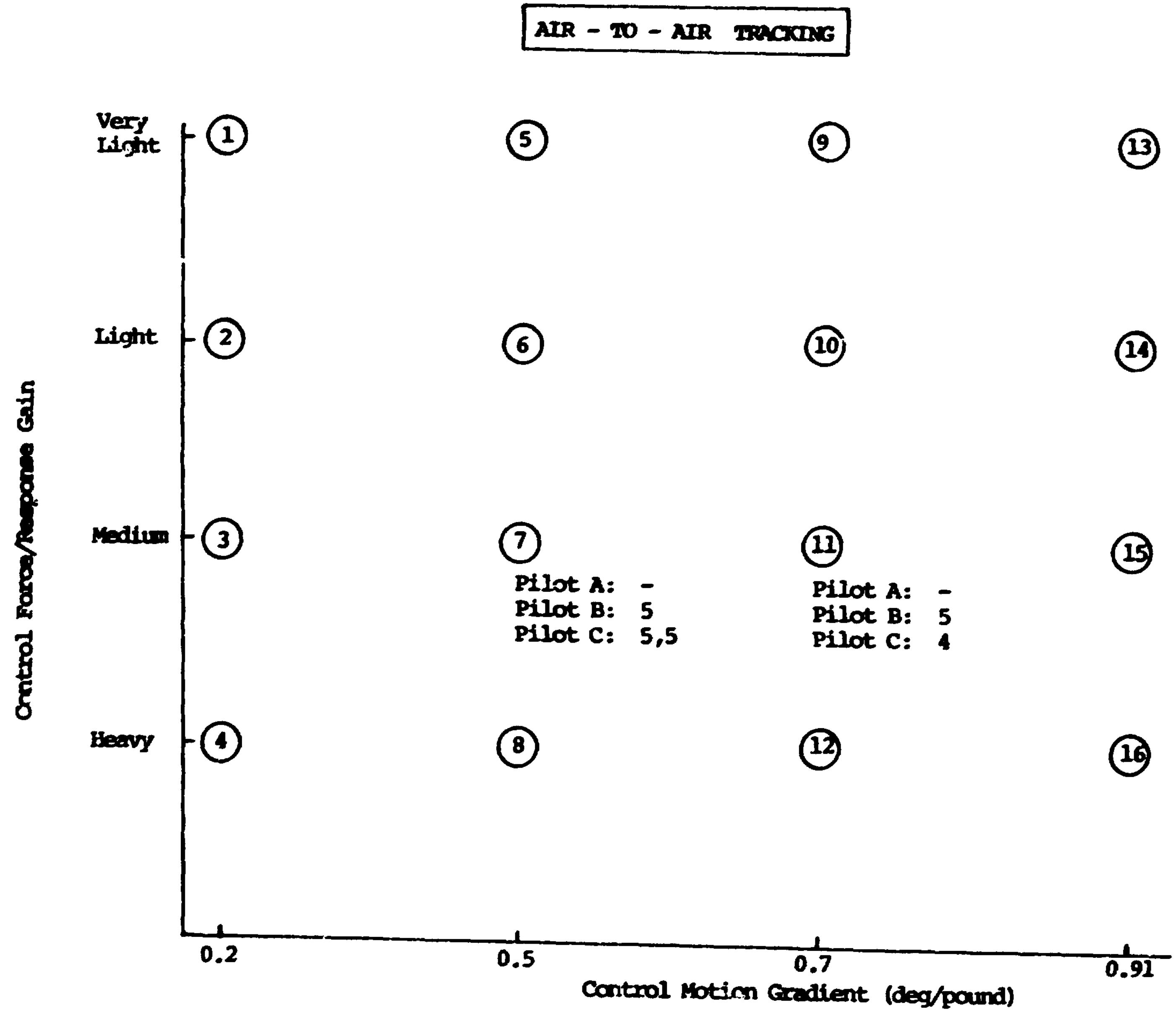


Figure A7 Pilot Ratings With One Pound Breakout Force

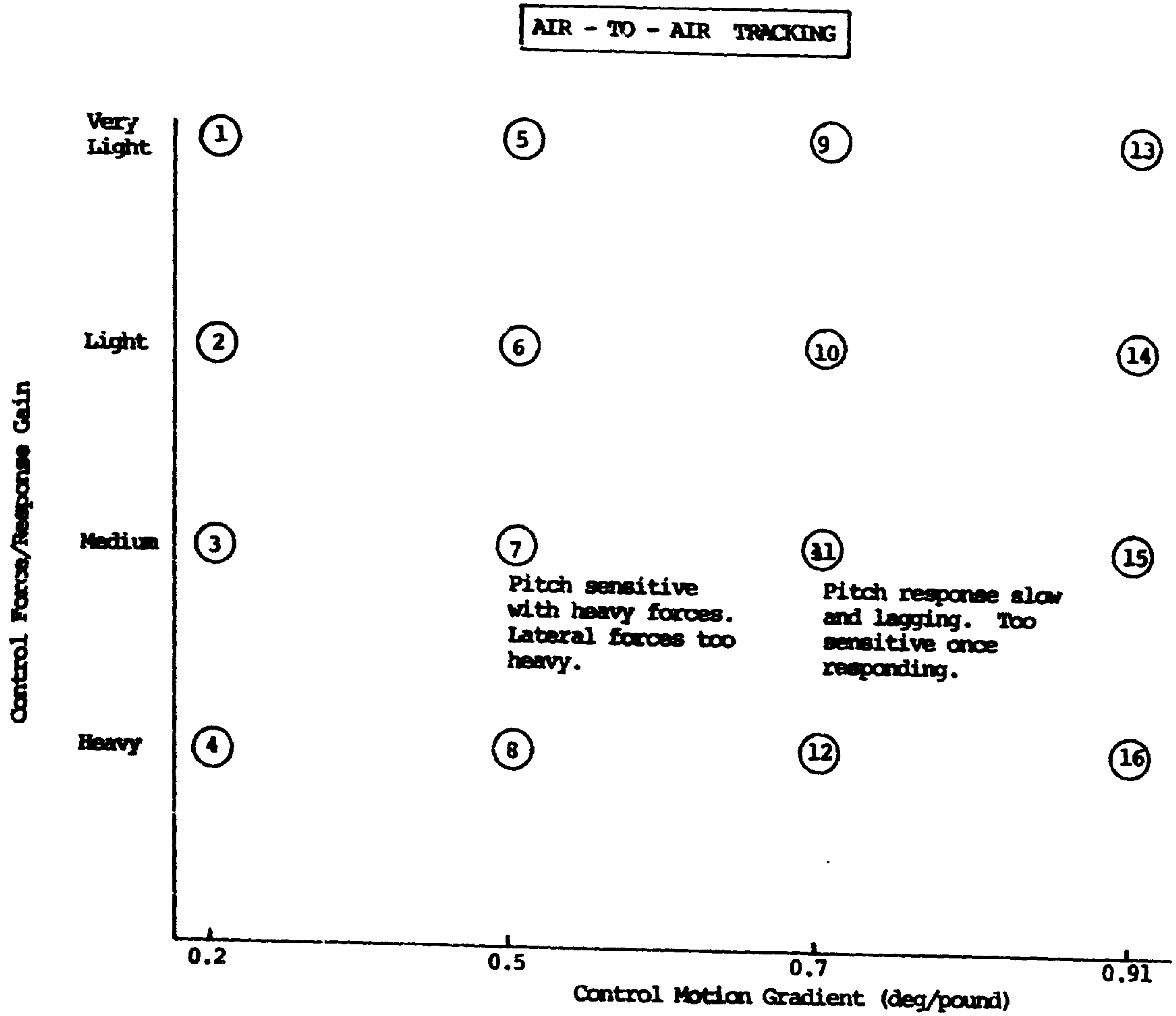


Figure A8 Pilot Comments With One Pound Breakout Force

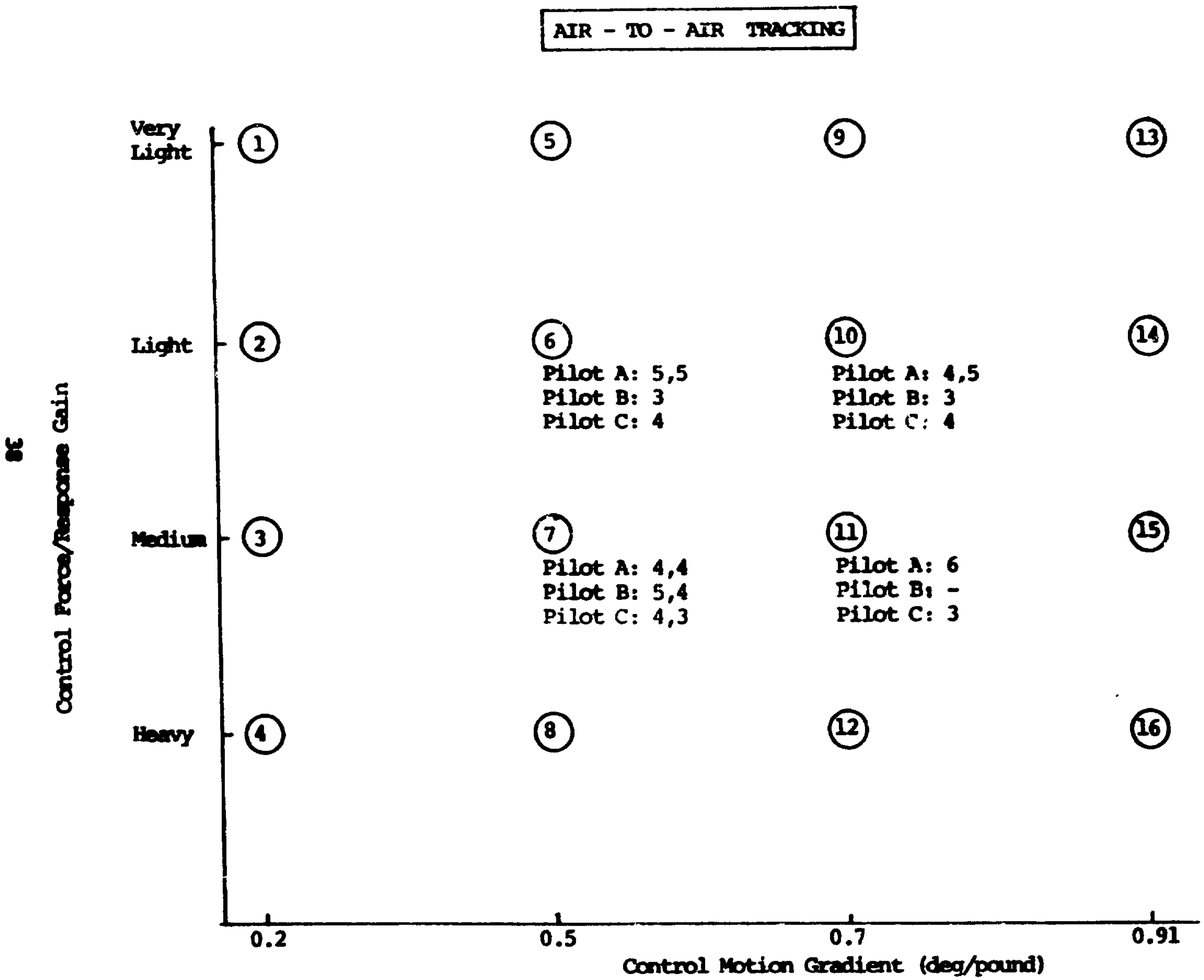


Figure A9 Pilot Ratings With Lighter Lateral Force Gradients

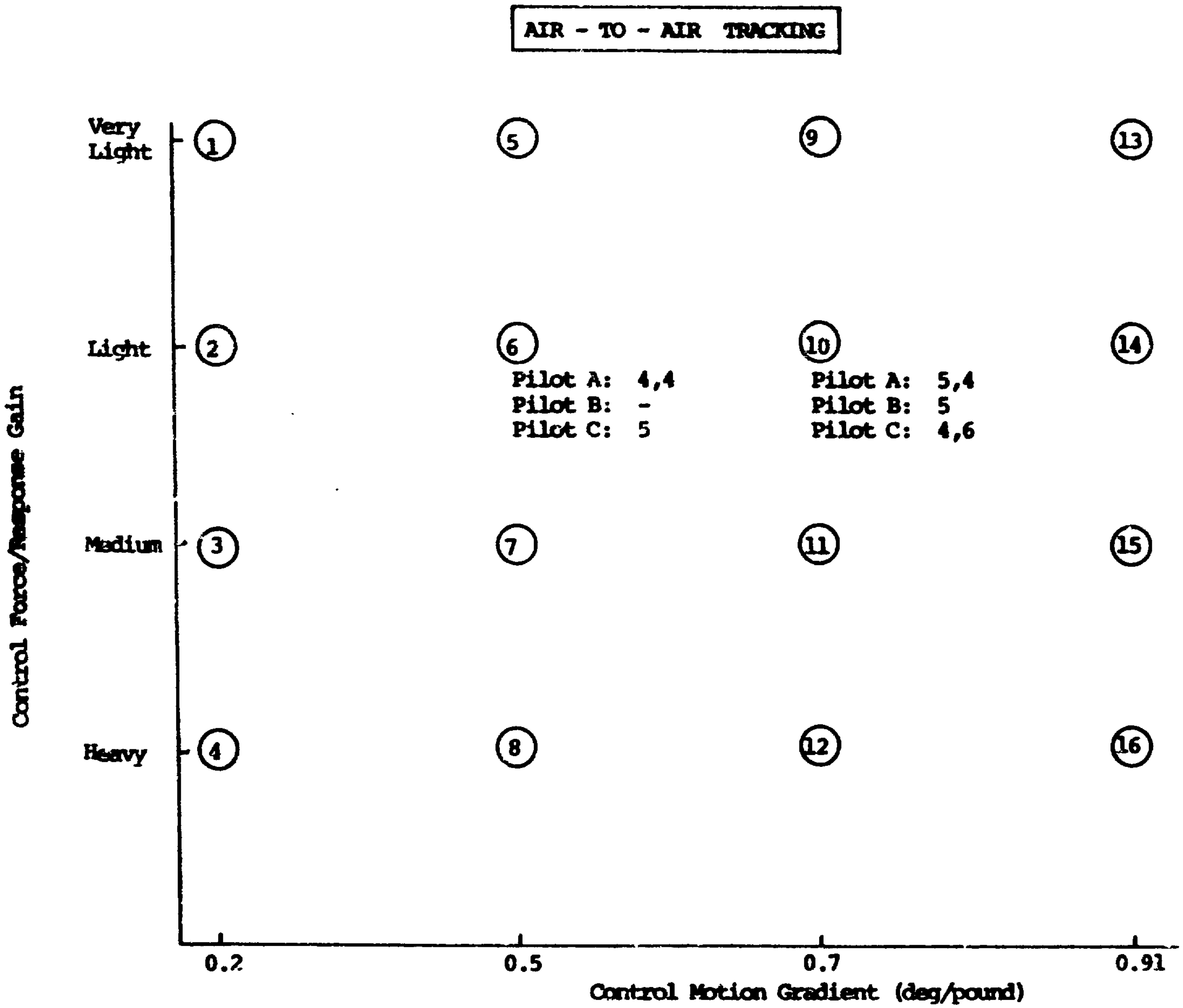


Figure A10 Pilot Ratings With Heavier Lateral Force Gradients

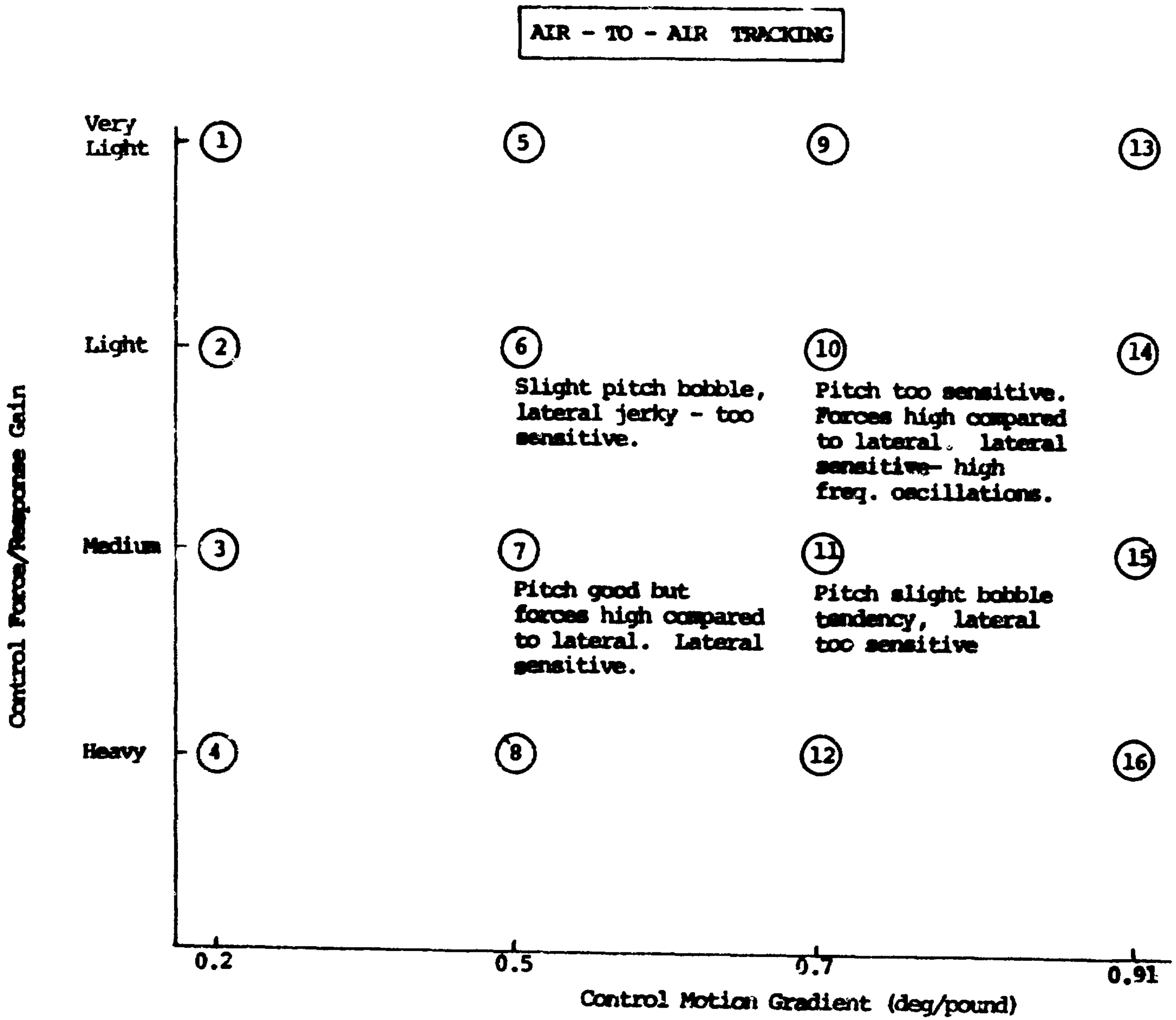


Figure A11 Pilot Comments With Lighter Lateral Force Gradients

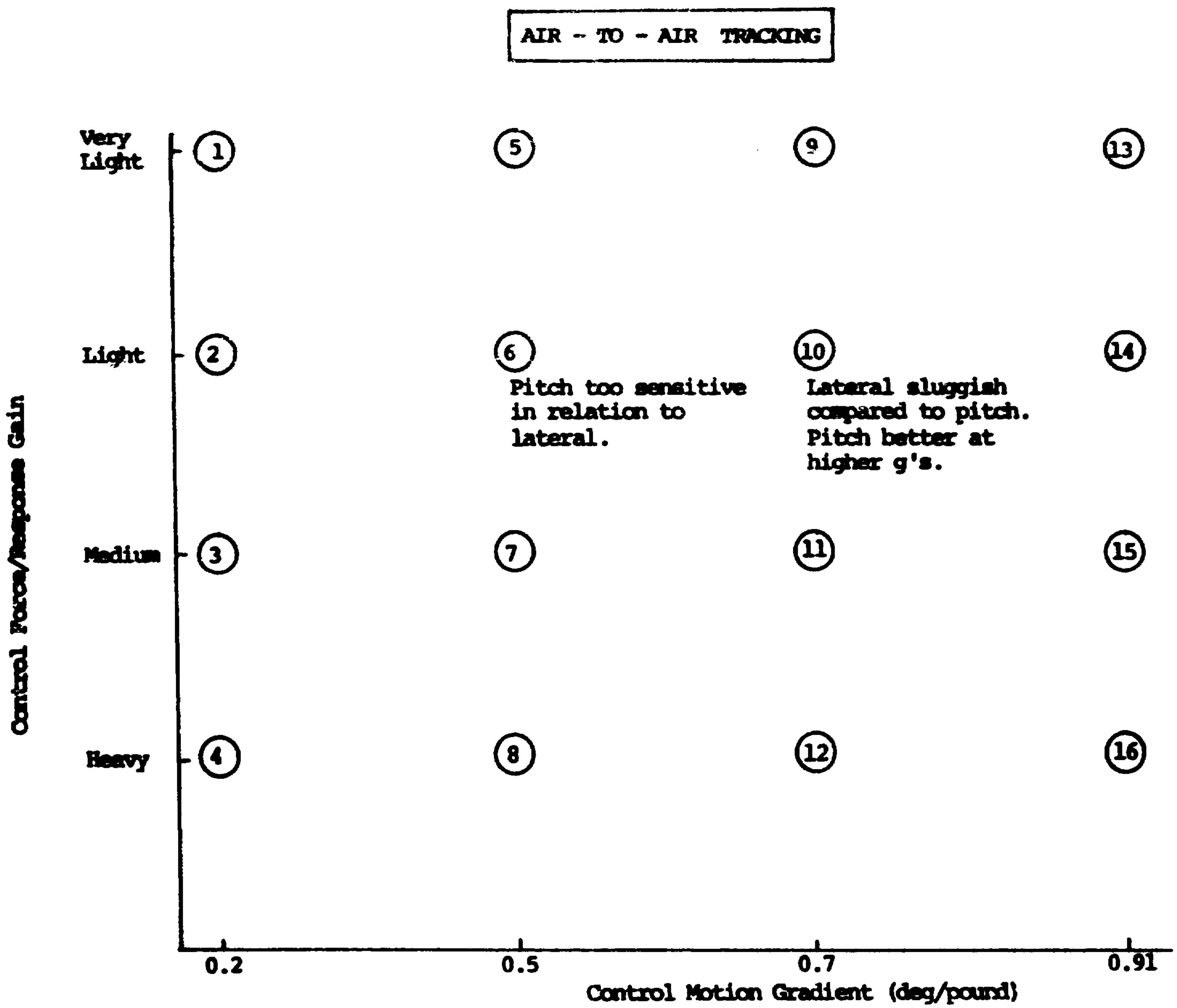


Figure A12 Pilot Comments With Heavier Lateral Force Gradients

AIR-TO-AIR TRACKING

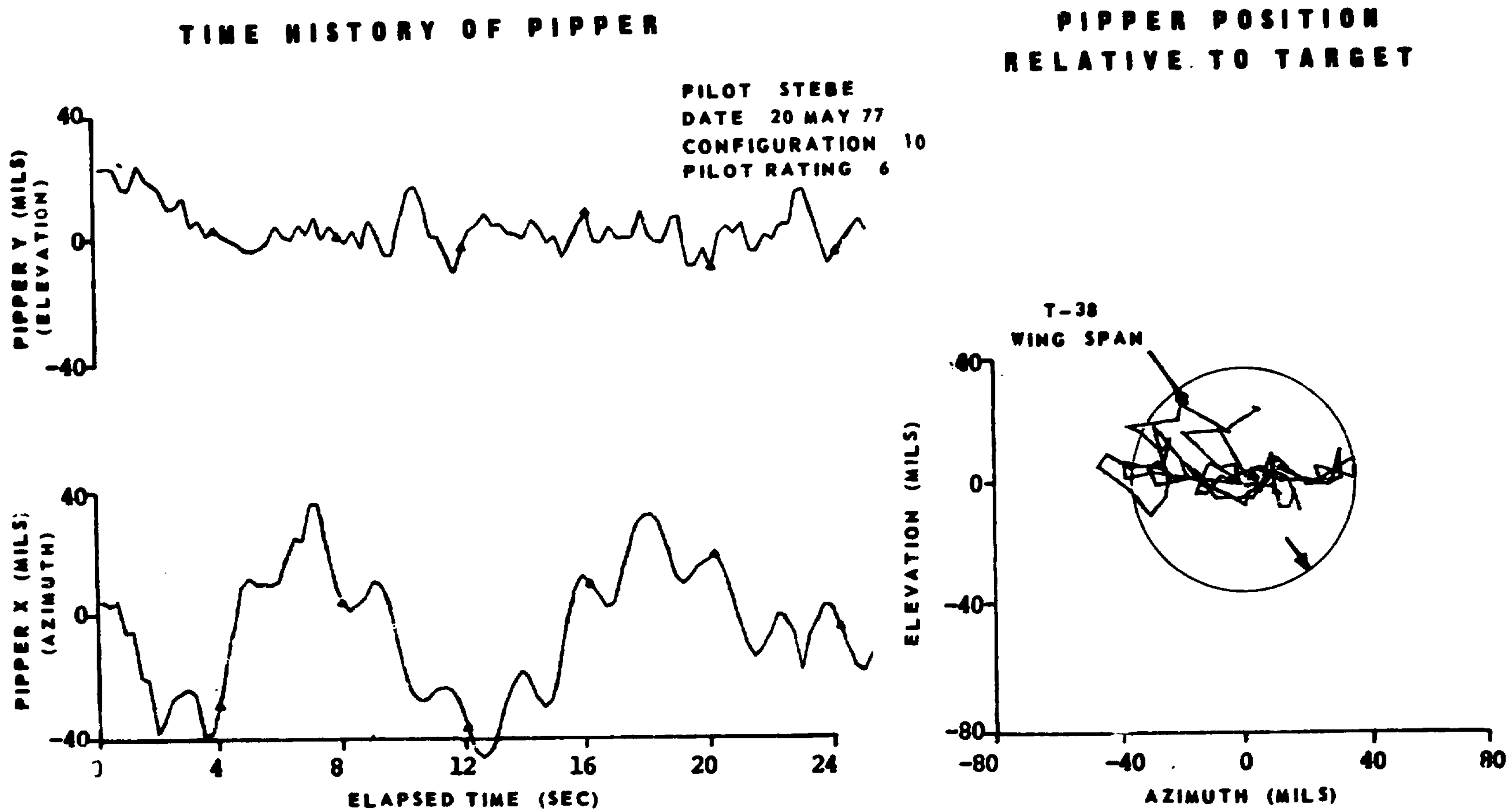


FIGURE A13 ATAGAS PLOTS OF PIPPER MOTION

AIR-TO-AIR TRACKING

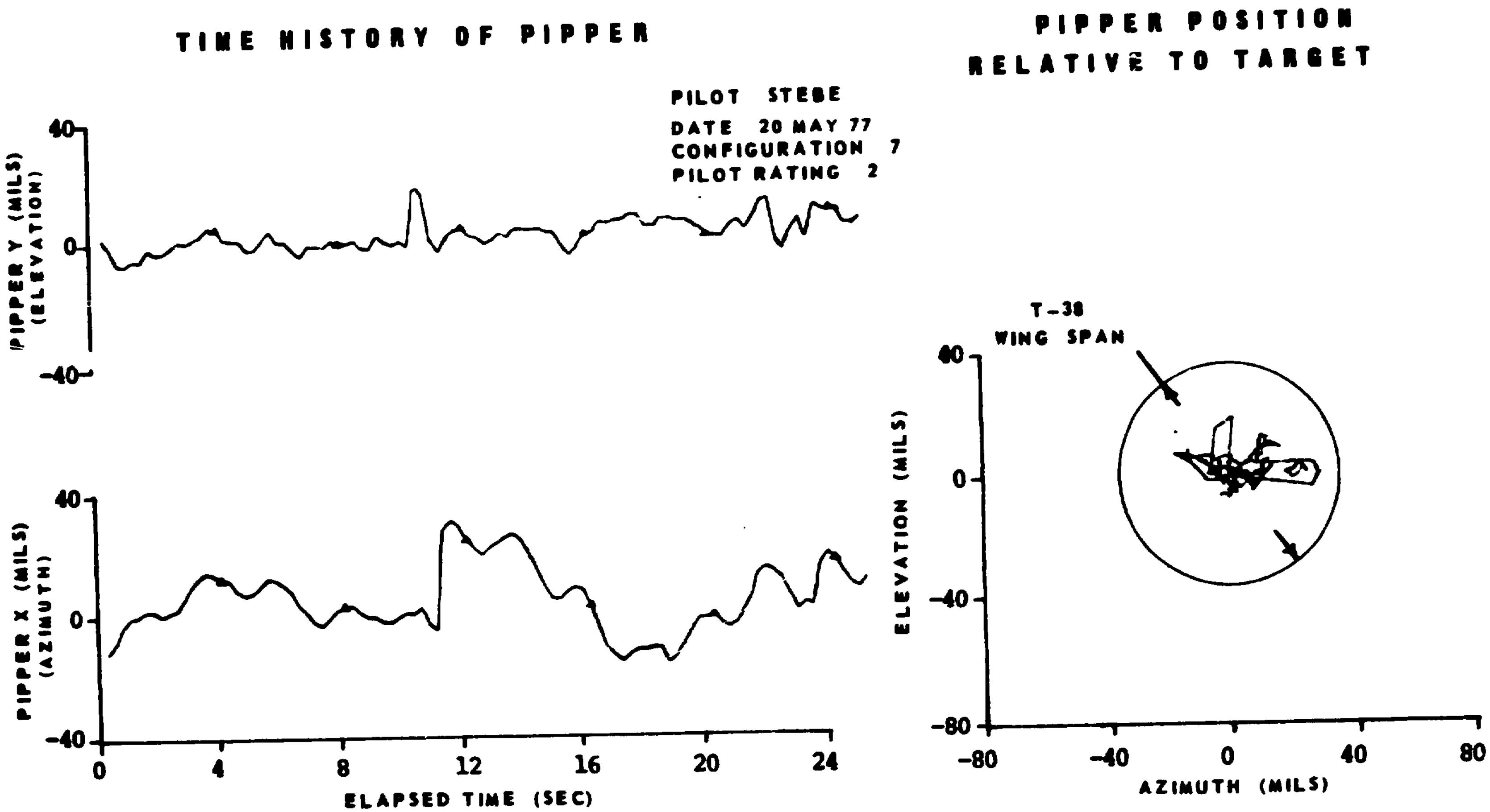
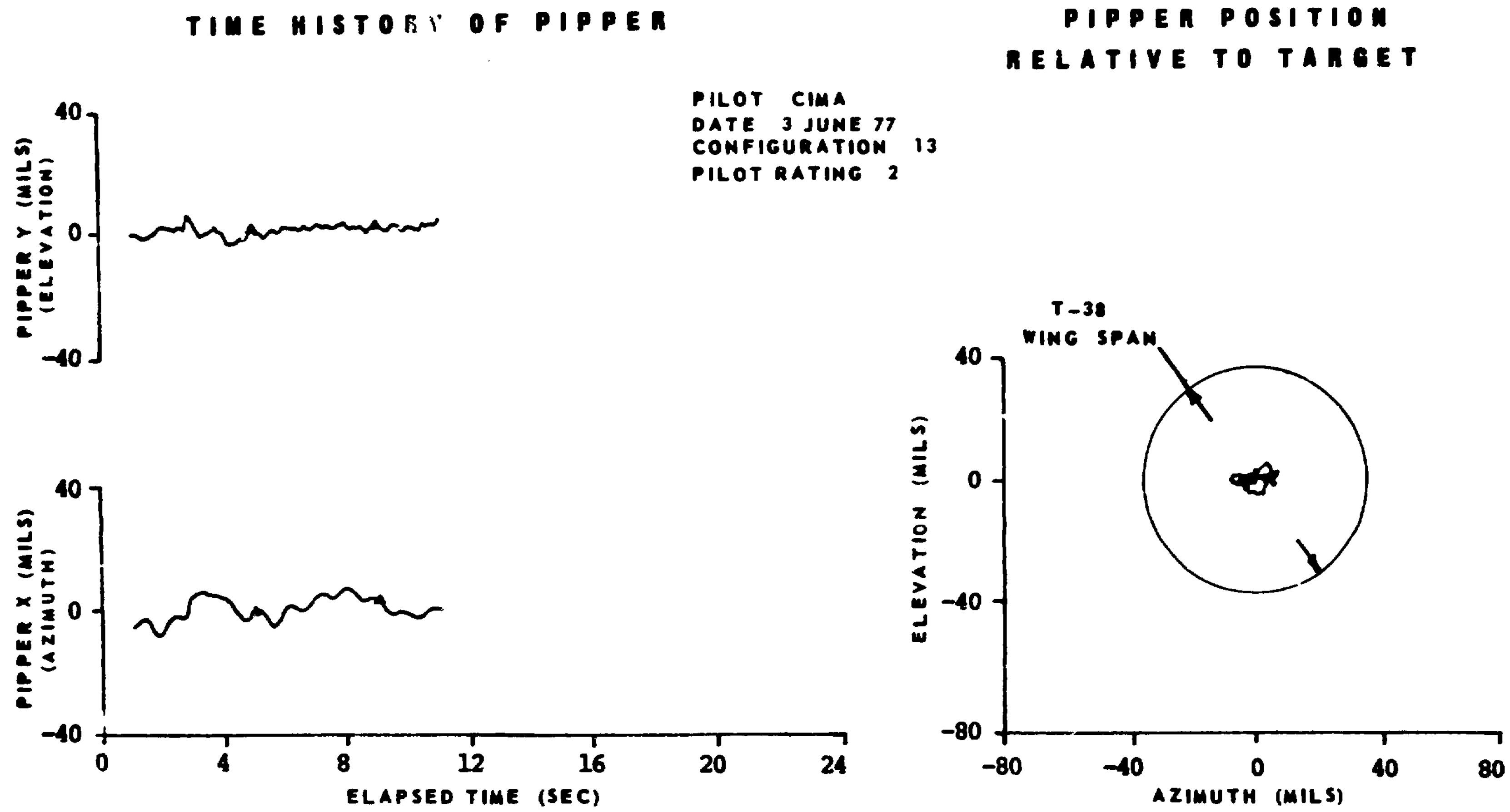


FIGURE A14 ATAGAS PLOTS OF PIPPER MOTION

AIR-TO-AIR TRACKING



PILOT CIMA
DATE 3 JUNE 77
CONFIGURATION 13
PILOT RATING 2

FIGURE A15 ATAGAS PLOTS OF PIPPER MOTION

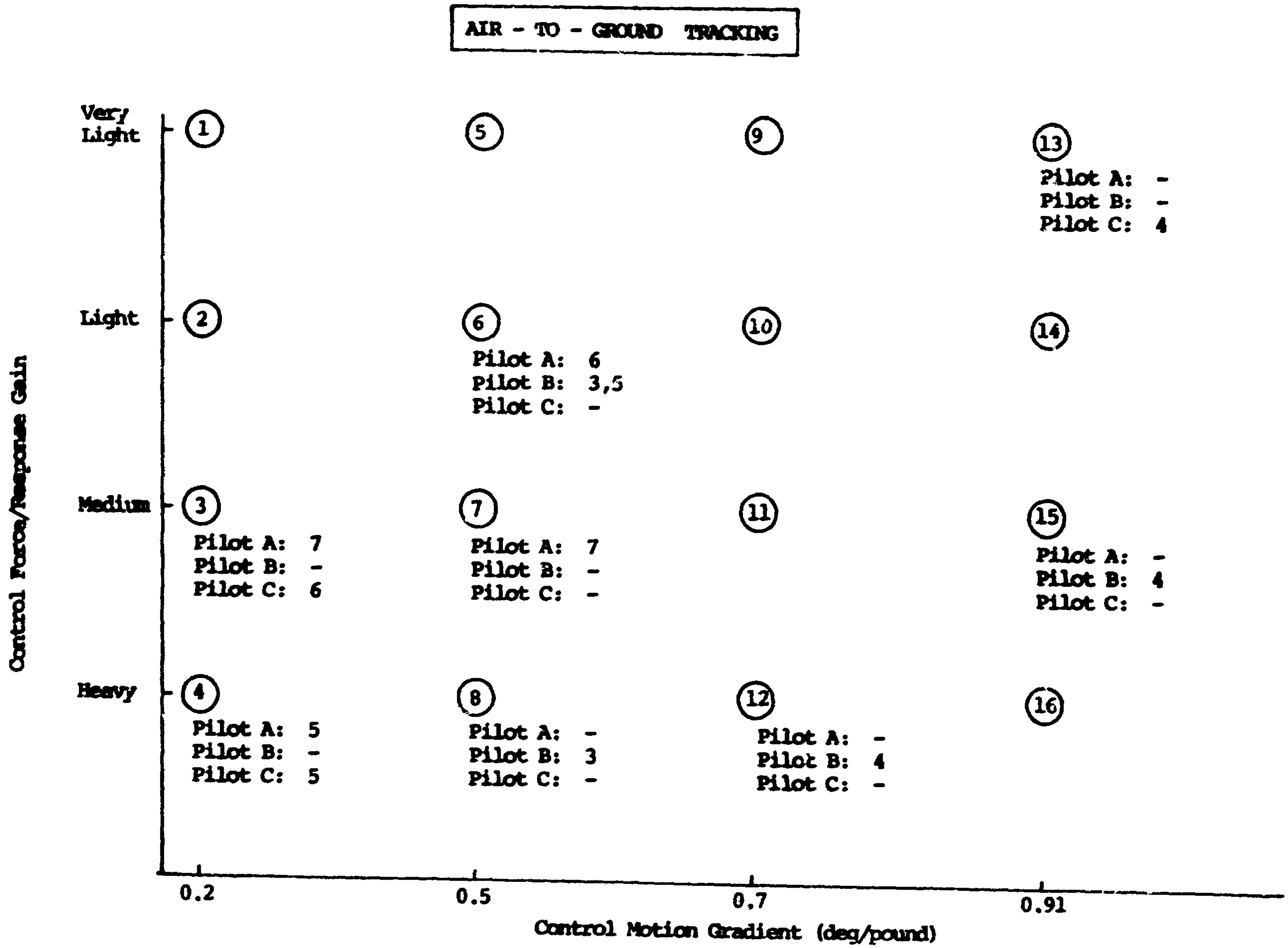


Figure A16 Individual Pilot Ratings For Air-To-Ground

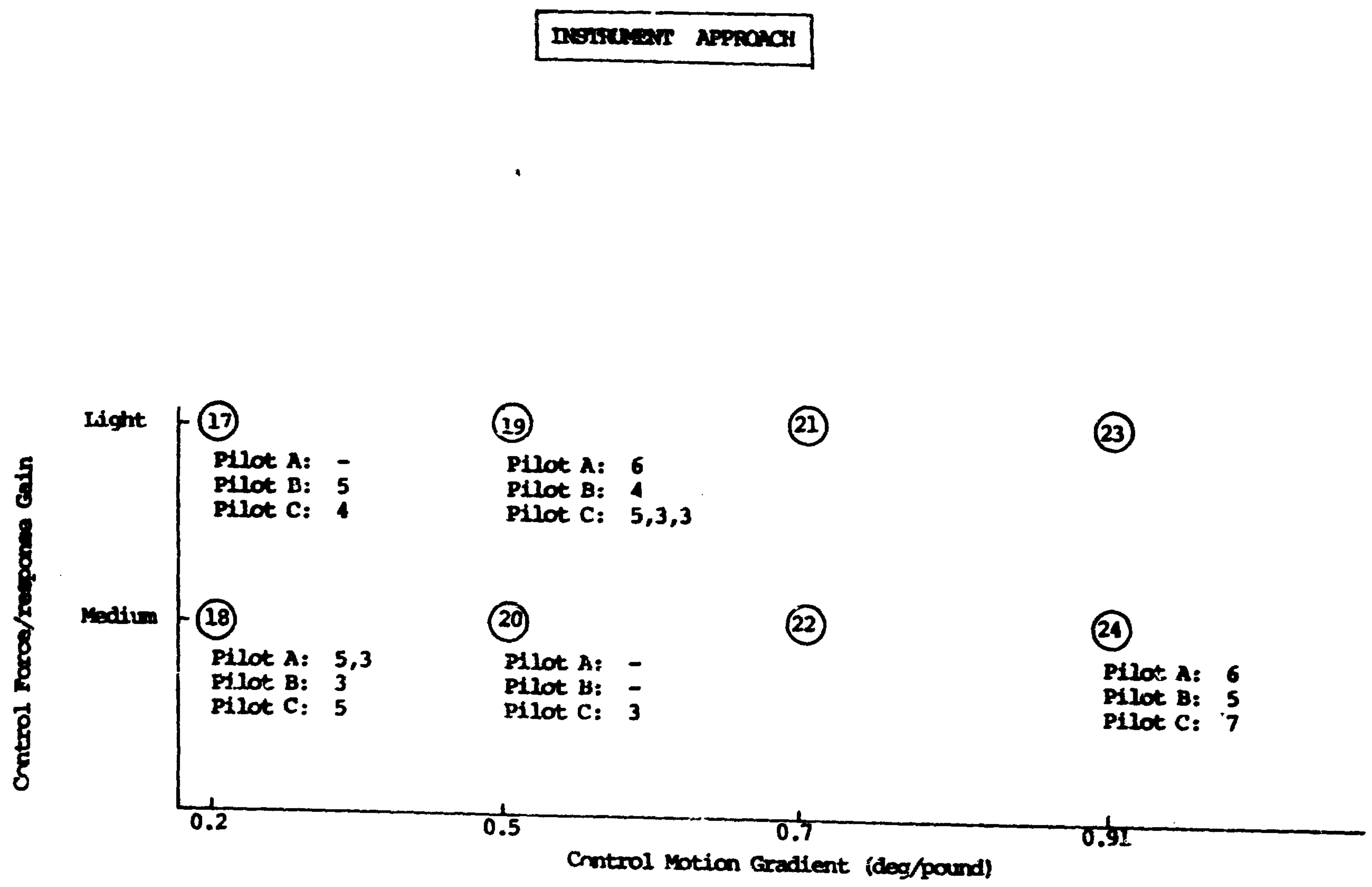


Figure A17 Individual Pilot Ratings For Instrument Approach

LANDING

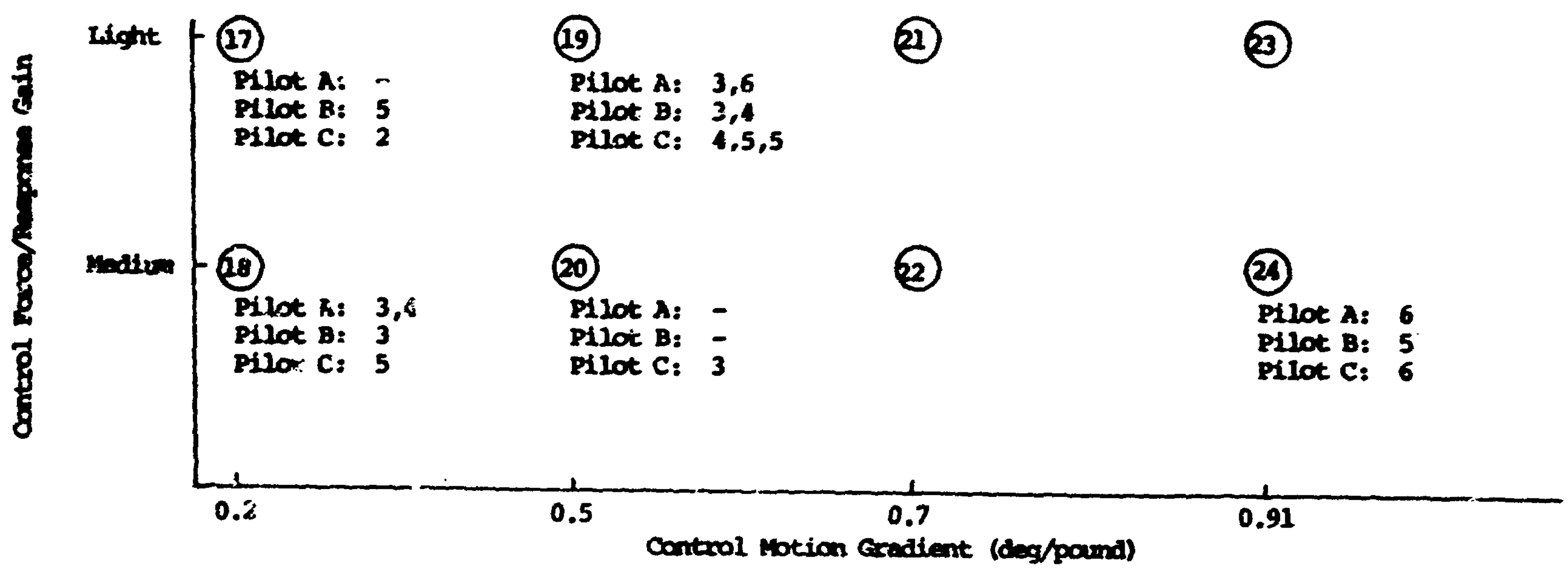


Figure A18 Individual Pilot Ratings For Landing

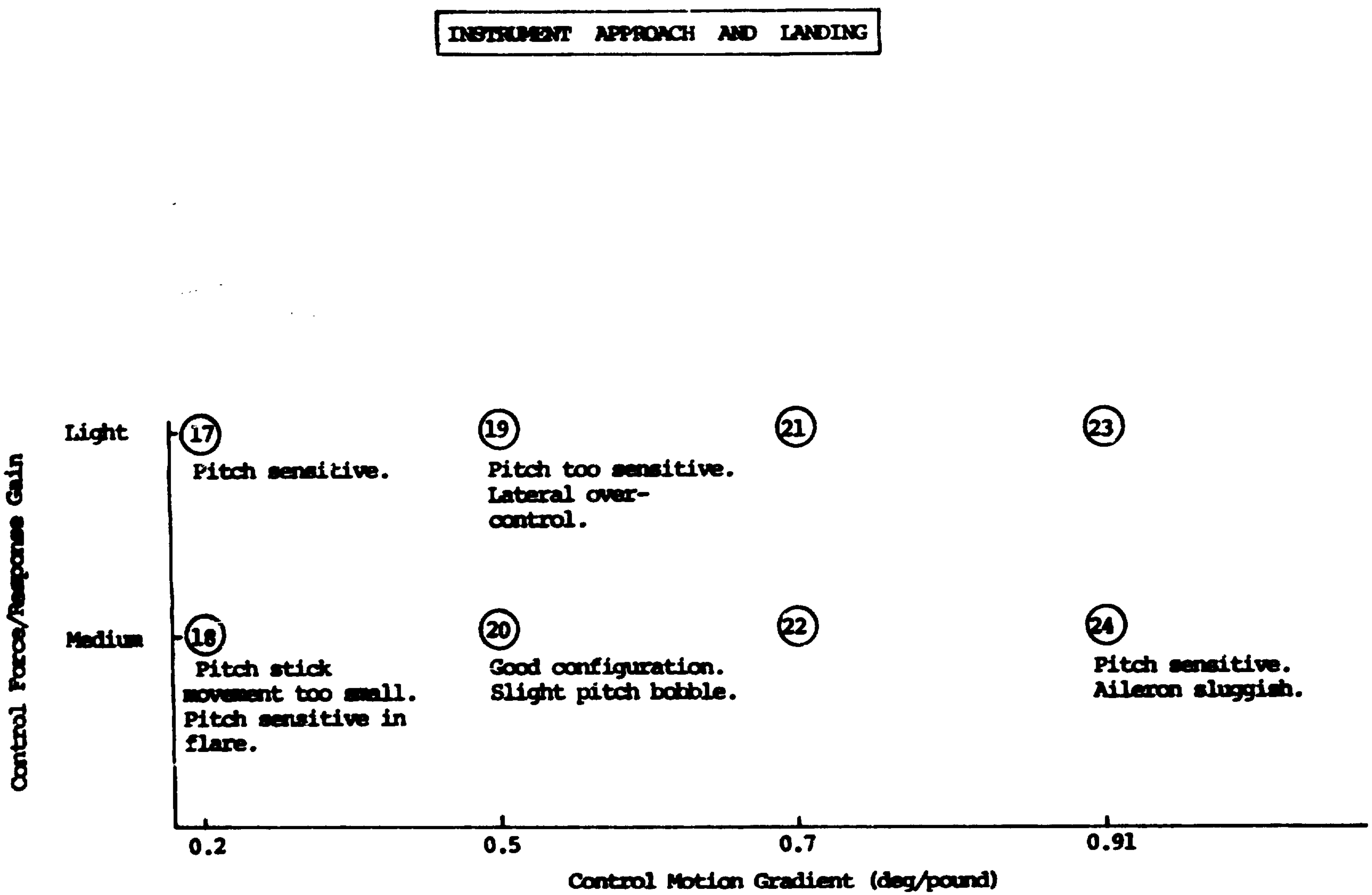


Figure A19 Typical Pilot Comments For Approach and Landing

APPENDIX B

TEST LIMITATIONS

APPENDIX B

TEST LIMITATIONS

General Limits:

a. Aircraft placard limitations were not exceeded.

b. All tasks were performed under VFR weather conditions.

Air-to-Air Tracking Task Limits:

a. Minimum separation was 1,000 ft during tracking.

b. Maximum NT-33A tracking speed was 350 KIAS.

c. Visual contact by the NT-33A crew was required.

Air-to-Ground Task Limits:

a. Minimum altitude 1,500 ft AGL.

b. Minimum airspeed in pattern 180 KIAS.

c. Maximum airspeed in pattern 350 KIAS.

d. Minimum roll in altitude 8,000 ft AGL.

e. Maximum stabilized dive angle 35 degrees.

f. Maximum pullout load factor 4.5 g.

APPENDIX C

TEST AIRCRAFT DESCRIPTION AND INSTRUMENTATION

APPENDIX C

TEST AIRCRAFT DESCRIPTION AND INSTRUMENTATION

TEST AIRCRAFT

The test aircraft, NT-33A USAF S/N 51-4120, was a modified T-33A jet trainer capable of reproducing the dynamic response and control system characteristics of different aircraft. The static and dynamics responses of the basic T-33A were modified by a response feedback variable stability system. The variable stability system positioned the control surfaces through full authority electrohydraulic servos.

The normal front cockpit flight controls were disconnected from the NT-33A control system and were replaced by a variable force and deflection fly-by-wire side stick controller used to perform this evaluation. The side stick is shown in figures C1 and C2. Motion was available in both pitch and roll with force gradients in each axis that could be varied independently. The pivot point for the longitudinal and lateral axis was the stick base. Control force gradients were achieved through an electrohydraulic system built into the controller. Force commands were used in both axes, and force/response gains were not affected by changes in the feel system force/displacement gradients. The side stick controller characteristics were changed in flight from the rear cockpit by the Calspan safety pilot.

INSTRUMENTATION

A fixed depression gunsight (shown in figure C3) was used as an aiming reference during the Category A tracking tasks. A 15 mil sight depression angle was used to reduce the "pendulum effect" and its influence on the pilot ratings. The same depression setting was used for both air-to-air and air-to-ground tracking.

A 16 mm gunsight camera operated at 4 frames per second was used to record pipper azimuth and elevation offset from the target during each Category A tracking task.

A cassette tape voice recorder was used to record pilot comments during and after the tracking task and to record the Cooper-Harper rating for each configuration.

A 50-channel Consolidated Electrodynamics Corporation type 5-119P3-50 oscillograph was used to record pitch rate, roll rate, longitudinal stick force, lateral stick force, elevator deflection, aileron deflection, rudder deflection and normal acceleration during the tracking task and aircraft calibration tests. Paper speed was 1.0 inch per second.

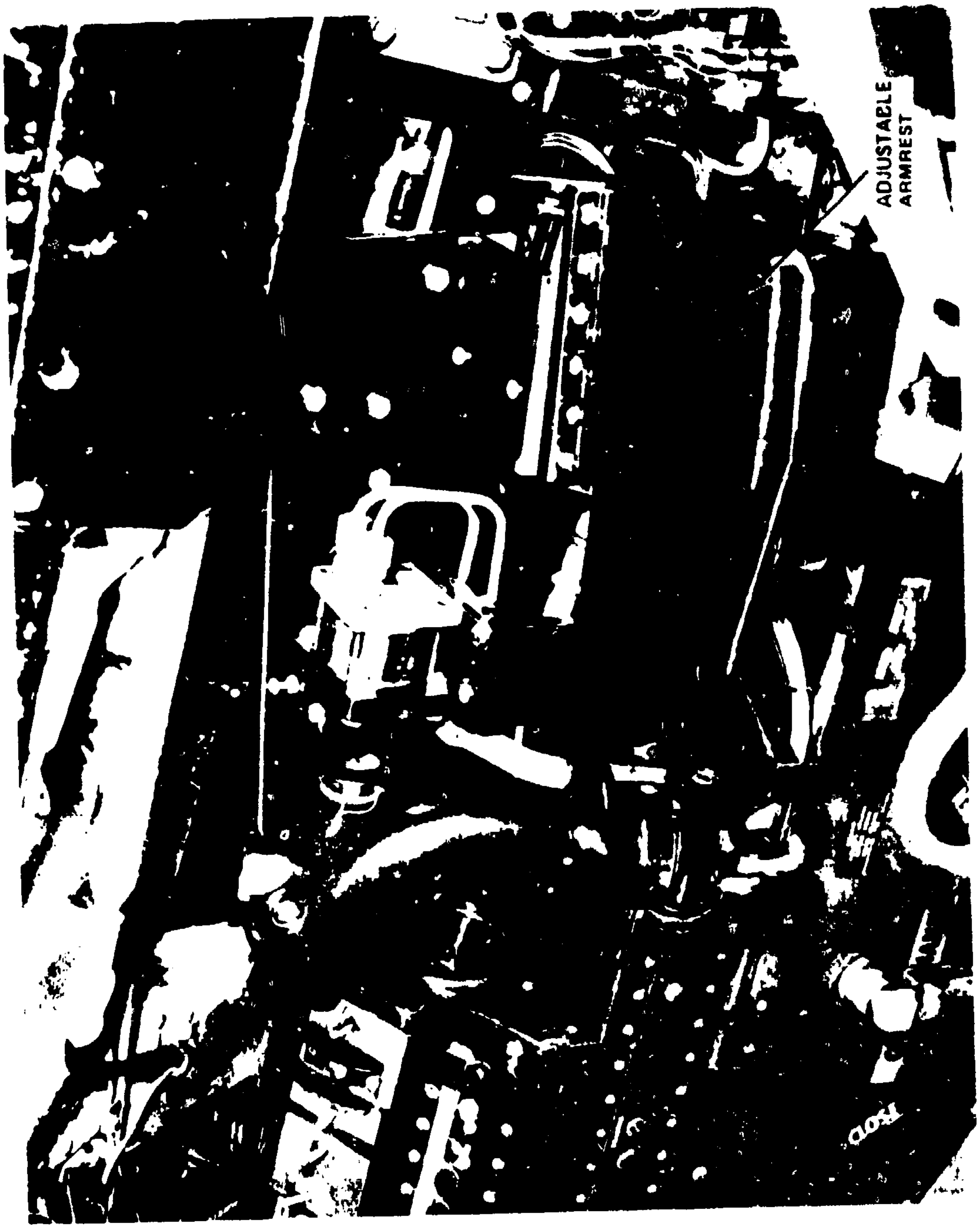


Figure C1 Side Stick Controller

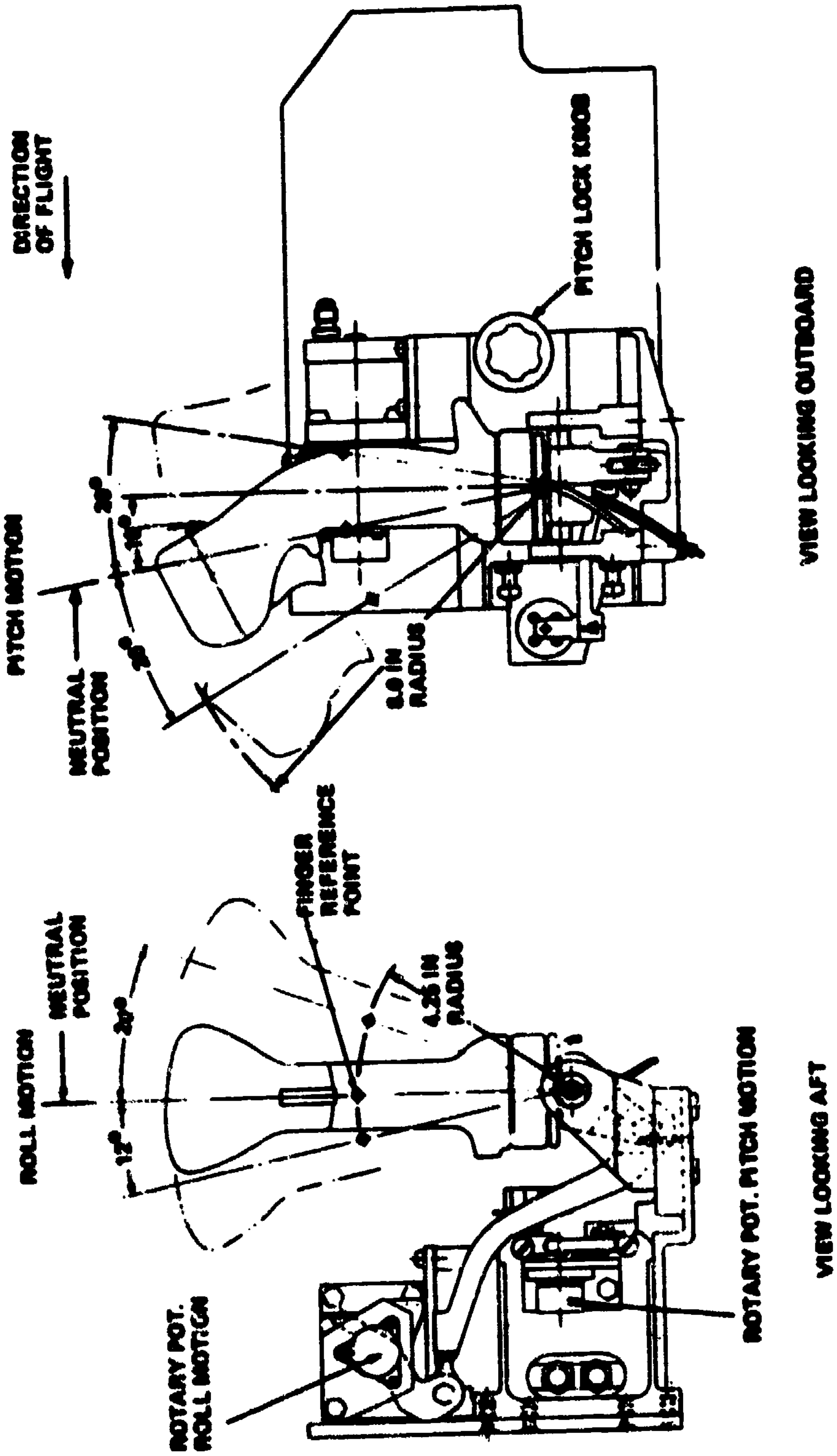


Figure C2 Side Stick Controller

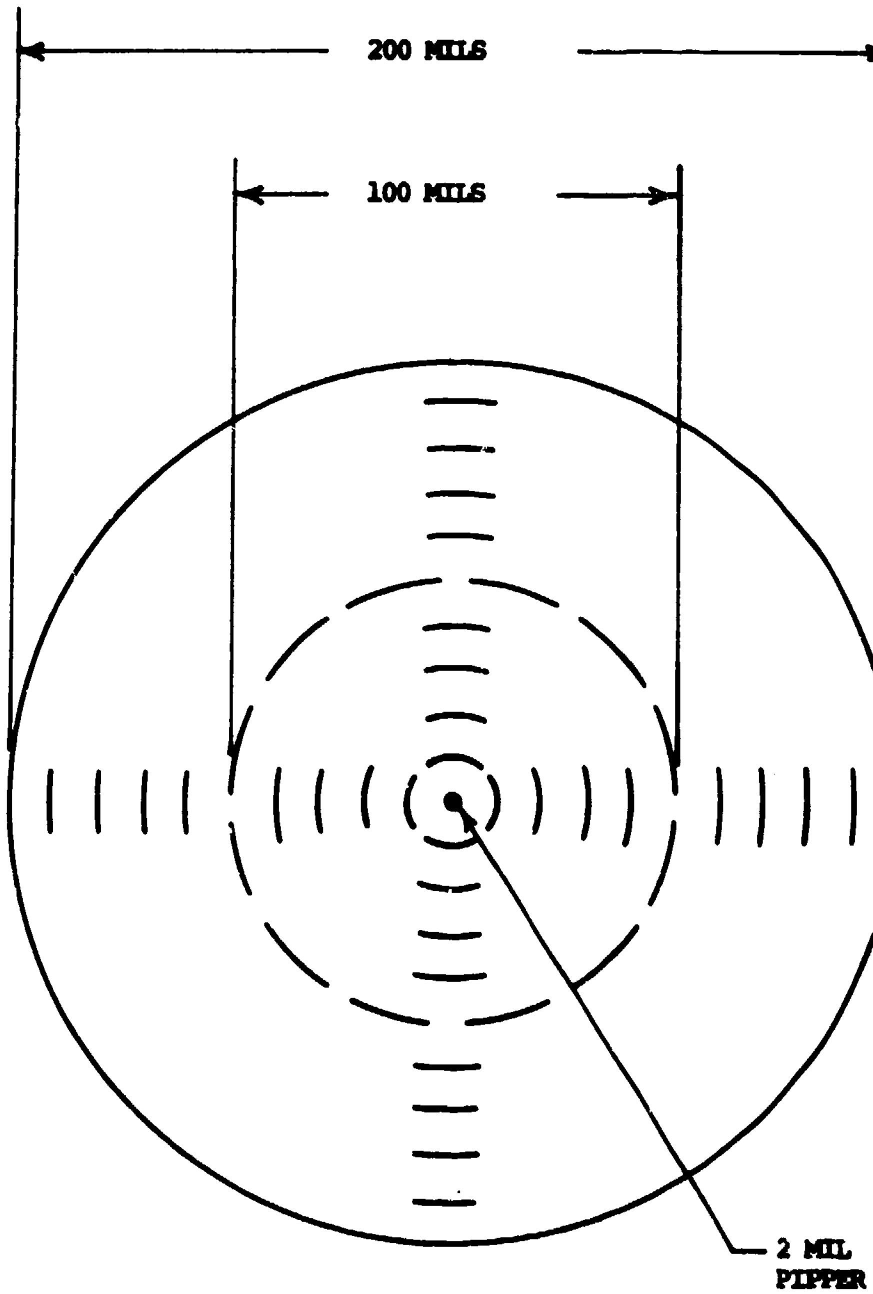


Figure C3 MT-33A Gunsight Reticle

APPENDIX D

DEBRIEFING GUIDES

HANDLING QUALITIES DEBRIEFING OUTLINE

The following debriefing outline may be used to evaluate defined test objectives as well as "normal" flying tasks which are performed incident to the planned tasks (such as take-off, climb, cruise, formation flight to the test area, descent, landing, etc.).

1. TASK

Description of the flight phase, subphase, or specific task being evaluated.

2. TEST CONDITIONS

What were the test conditions?

a. FLIGHT CONDITIONS Altitude, airspeed/Mach number, attitude, angle of attack, etc.

b. CONFIGURATION Aircraft and flight control system configuration and state. (Loading, c.g., gear and flaps, power setting, augmentation on/off, test gains, normal or failure state, etc.)

c. ENVIRONMENT (Turbulence level [use turbulence rating scale], wind shear, cross-winds, lighting, sun angle, etc.)

3. TEST TECHNIQUE

How was the test performed? (Was a special technique used? - refer to debriefing checklist for that technique.)

a. UNPLANNED DIFFERENCES Did execution of the test differ from what was planned?

1) WHY ? (Airplane could not achieve planned test conditions; test conditions were too stringent or too precise to be achieved and/or maintained; test was poorly designed, or poorly flown, etc.)

4. PILOT COMMENTS

Pilot comments on his ability to perform the identified task. (Desirable characteristics, problems, difficulties, unusual or unexpected or troublesome airplane responses, PIO tendencies [use PIO rating scale], etc.)

(continued on reverse)

a. SHORTCOMINGS How might handling qualities be improved? (Improved harmony, quicker or slower response, reduced adverse yaw, improved gust response, etc.)

b. COCKPIT PROBLEMS Was cockpit interfacing a factor in performing the task? (Controls, selectors, instrument location or presentation, crew comfort, geometry, etc.)

c. ENVIRONMENTAL PROBLEMS Were environmental conditions a factor in performing the task?

d. OTHER PROBLEMS Were there other factors which influenced the performance of the task? (Unexpected failure states, transients, afterburner slow to light, wake turbulence, etc.)

e. PILOT RATING Cooper-Harper rating for the task, based on progression through the decision logic (refer to Cooper-Harper rating scale).

1) **AXIS** Is this a single-axis or a multi-axis rating?

2) **INFLUENCES** How do 4.b., 4.c., and 4.d. above affect the Cooper-Harper rating?

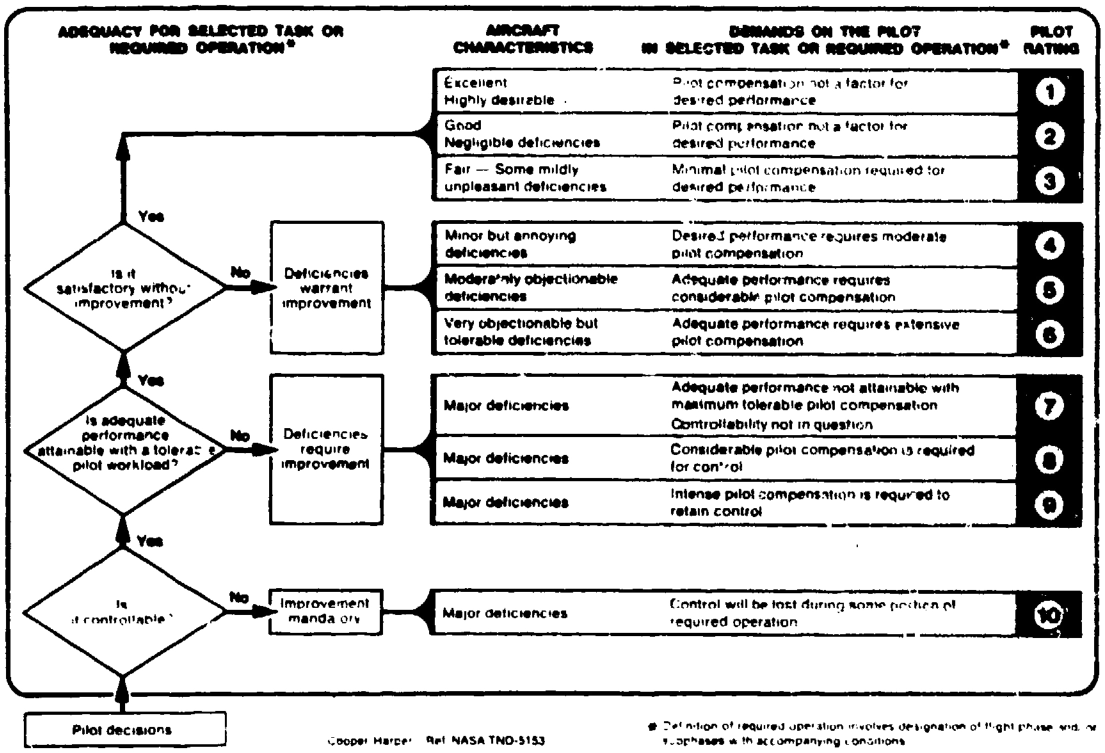
f. CONFIDENCE LEVEL How confident is the pilot of his Cooper-Harper rating (use pilot confidence rating scale)?

1) **WHY ?** If not confident, why not? (Did the test provide an adequate opportunity for evaluation?)

2) **TEST IMPROVEMENTS** How could the test be improved to permit a better evaluation?

* Reproduced from Reference 5: Twisdale, Thomas R., Preflight Briefing and Postflight Debriefing Outlines for Handling Qualities Testing and Evaluation, Flight Test Technology Branch, Office Memo, Air Force Flight Test Center, Edwards AFB, California, February 1977.

HANDLING QUALITIES RATING SCALE



From reference 6:

Cooper, G.E., and Harper, R.P. Jr., The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities, NASA TN D-5153, Ames Research Center, Moffett Field, California, April 1969.

APPENDIX E

PILOT BACKGROUND INFORMATION

NT-33A

EVALUATION PILOT QUESTIONNAIRE

Personal Data

NAME Stebe, J.T. (Pilot A) RANK Capt SERVICE USAF

AGE 33 TOTAL FLYING TIME 3000 hr

Detailed Flying Time Breakdown
(List most recent aircraft first)

AIRCRAFT	TIME (hr)
U-2	500
T-33	450
B-66	275
T-38	1775

Approximate Total Number of Air-to-Air Sorties 0

Approximate Total Number of Air-to-Ground Sorties 0

Approximate Total Number of Aerial Refuelings 100

Approximate Total Number of ILS Approaches 150

NT-33A

EVALUATION PILOT QUESTIONNAIRE

Personal Data

NAME LeBeau, T.J. (Pilot B) RANK Capt SERVICE USAF

AGE 33 TOTAL FLYING TIME 1500 hr

Detailed Flying Time Breakdown
(List most recent aircraft first)

AIRCRAFT	TIME (hr)
RF-4C	27
T-38A	61
B-52G/D	1170

Approximate Total Number of Air-to-Air Sorties	
Approximate Total Number of Air-to-Ground Sorties	
Approximate Total Number of Aerial Refuelings	80
Approximate Total Number of ILS Approaches	200

NT-33A

EVALUATION PILOT QUESTIONNAIRE

Personal Data

NAME Cima, W.M. (Pilot C) RANK Lt SERVICE USN

AGE 30 TOTAL FLYING TIME 1100 hr

Detailed Flying Time Breakdown
(List most recent aircraft first)

AIRCRAFT	TIME (hr)
T-38A	60
RF-4C	25
F4J	700

Approximate Total Number of Air-to-Air Sorties	300
Approximate Total Number of Air-to-Ground Sorties	100
Approximate Total Number of Aerial Refuelings	200
Approximate Total Number of ILS Approaches	200

APPENDIX F

LIST OF TEST SORTIES

	NT-33A		TARGET	
DATE	CREW	HOURS	TYPE/TAIL NO.	CREW
13 May 77	Cima/Harper	1.5	T-38/934	Stebe/Banta
17 May 77	LeBeau/Hall	1.7	T-38/153	Stebe/Waldruff
17 May 77	Stebe/Hall	1.7	T-38/153	LeBeau/Newman
18 May 77	Cima/Hall	1.8	T-38/154	Beaulier/Pavel
18 May 77	LeBeau/Hall	1.6	T-38/579	Cima/Miller
19 May 77	Cima/Hall	1.8	T-38/575	LeBeau/Miller
19 May 77	Stebe/Hall	1.6	T-38/575	Robert/Jacob
20 May 77	LeBeau/Hall	1.7	T-38/154	Collius/Jacob
20 May 77	Stebe/Hall	1.5	T-38/154	Muldrow/Miller
23 May 77	LeBeau/Hall	1.6	T-38/943	Spencer/Jacob
23 May 77	Stebe/Hall	1.5	T-38/375	Pollock/Miller
24 May 77	Stebe/Hall	1.5	RF-4/626	Cooper/Nelson
24 May 77	LeBeau/Hall	1.7	T-38/579	Collius/Jacob
25 May 77	Cima/Hall	1.6	T-38/954	Borowski/Jacob
25 May 77	Stebe/Hall	1.5	T-38/579	Neely/Miller
26 May 77	Cima/Hall	1.4	T-38/559	Behler/Jacob
26 May 77	Stebe/Hall	1.3	T-38/559	Collins/Miller
27 May 77	Cima/Hall	1.5	T-38/158	Behler/Poch
31 May 77	Cima/Hall	1.5	T-38/954	Borowski/Teague
1 Jun 77	LeBeau/Hall	1.6	T-38/954	Vangeldrop/Miller
1 Jun 77	LeBeau/Hall	1.5	T-38/856	Barns/Hamlin
3 Jun 77	Cima/Hall	1.3	T-38/559	Barns/Waldruff
3 Jun 77	Stebe/Hall	1.3	T-38/558	Neely/Miller

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Description	Units
AFFDL	Air Force Flight Dynamics Laboratory	- - -
AFFTC	Air Force Flight Test Center	- - -
AGL	above ground level	- - -
ATAGAS	Air-to-Air Gunnery Analysis System	- - -
F_{as}	aileron stick force	lb
F_{es}	elevator stick force	lb
HQDT	handling qualities during tracking	- - -
ILS	instrument landing system	- - -
KIAS	knots indicated airspeed	- - -
MSL	mean sea level	ft
n_z	normal acceleration	g
p	roll rate	deg/sec
TPS	test pilot school	- - -
UHF	ultrahigh frequency	- - -
VFR	visual flight rules	- - -
α	aircraft angle of attack	deg
β	aircraft angle of sideslip	deg
δ_{as}	lateral stick deflection	deg
δ_{es}	longitudinal stick deflection	deg
ζ_d	Dutch roll damping ratio	dim
ζ_p	phugoid damping ratio	dim
ζ_ϕ	damping ratio of numerator quadratic term in the p/F_{as} transfer function	dim

Item	Description	Units
ζ_{sp}	short period damping ratio	dim
τ_R	roll mode time constant	sec
τ_{θ_2}	lead time constant in θ/F_{es} transfer function	sec
τ_s	spiral mode time constant	sec
ϕ	aircraft bank angle	deg
ω_d	Dutch roll natural frequency	rad/sec
ω_p	phugoid natural frequency	rad/sec
ω_{sp}	short period natural frequency	rad/sec
ω_ϕ	natural frequency of numerator quadratic term in the ϕ/F_{as} transfer function	rad/sec